USDA NRCS
Natural Resources Conservation Service

United States
Department of Agriculture

6200 Jefferson NE, Room 305
Albuquerque, New Mexico
87109-3734
Phone: (505) 761-4400
Fax: (505) 761-4462

February 23, 1999

New Mexico Range Technical Note NO. 84

SUBJECT: ECS PUBLICATION, "LOCOWEED RESEARCH UPDATES AND HIGHLIGHTS"

Purpose: To distribute Range Technical Note No. 84.

Effective Date: When contents have been noted.

Filing Instructions: File in the Range Technical Note II binder.

The enclosed publication, "Locoweed Research Updates and Highlights" provides information on toxic rangeland Loco Weeds that will be useful to field office, range conservationist, and soil survey offices.

If you require additional information and/or assistance concerning this publication please contact State Rangeland Management Specialist George Chavez at (505)761-4421, Email: fchavez@nm.nrcs.usda.gov.

KENNETH B. LEITING
Assistant State Conservationist
for Technical Services

Dist:
ASTC/FO (2)
DC (37)
Ecological Sciences Division, Washington, DC (2)
Adjoining States – UT, CO, TX, OK, AZ (1 each)
Technical Services (1 file) George Chavez, State Rangeland Management Specialist, Albuquerque, NM
Herman Garcia, Rangeland Management Specialist, Albuquerque, NM
Saundra Morris, Rangeland Management Specialist, Albuquerque FO
Elizabeth Wright, Rangeland Management Specialist, Tucumcari FO

Locoweed Research
Updates and Highlights

Edited by
Tracy M. Sterling and David C. Thompson

Research Report 730

Agricultural Experiment Station
Cooperative Extension Service

January 1999

Contents

Preface

Locoweed Research: Updates and Highlights reports on research concerning the toxic, rangeland weeds, white locoweed (*Oxytropis sericea* Nuttall) and woolly locoweed (*Astragalus mollissimus* Torrey). White locoweed also is referred to as white-point loco or silky crazyweed. Woolly locoweed also is known as purple locoweed or woolly loco. An interdisciplinary team of scientists at New Mexico State University and the USDA's Poisonous Plant Laboratory in Logan, Utah have contributed to this publication. The team was charged with identifying economical, environmentally safe management methods that will reduce locoweed to acceptable levels on New Mexico rangeland as well as eliminate its toxic effects on livestock. This volume contains summaries of research findings from these scientists in the areas of biological control, chemical and grazing management, ecology, economics, physiology and toxicology.

We thank all the authors involved in this publication, and special thanks go to Natalie Johnson, Cathy Montes, and Brian Grayless of NMSU's Department of Agricultural Communications for their editing and layout expertise.

T.M.S.
D.C.T.

Overview of Recent Locoweed Research

Gary Cunningham, Associate Dean and Director of the Agricultural Experiment Station and Interim Vice President for Research, New Mexico State University

In the western United States, poisonous plants cause major economic losses to the livestock industry every year. Poisonous locoweeds and milkvetches in the genera *Astragalus* and *Oxytropis* are among the most destructive. Several species, including white and woolly locoweed, can increase in density, becoming dominant, given appropriate environmental conditions and habitat. These plants are native to western rangelands, thus management to control their economic impact will require a thorough understanding of their ecology and toxicology.

Even low densities of these poisonous plants can cause substantial economic impact. Livestock may search out and consume individual plants in preference to grasses. Although some *Astragalus* are nontoxic, and some have other toxins, white and woolly locoweed contain swainsonine. This toxin damages the nervous system of affected animals. Stopping consumption or counteracting the effects of poisoning when it occurs is critical to eliminating the economic impact of these plants.

Management of locoweeds has proven difficult. These opportunistic, native species are genetically diverse and can occupy a wide variety of habitats. For the past century, ranchers, other land managers, and scientists have been looking for the elusive "silver bullet" to control locoweed problems. The verdict to date: No one solution is going to work everywhere! Many different approaches are being studied, including toxicology, chemical and biological control, grazing methods, physiology, and ecology to better understand how we can manage the entire system. The solution will likely be a combination of methods that can be employed as natural resources, economics, society, and technology change.

As we continue to work at maintaining the sustainability of our western rangelands as productive ecosystems, the active management of poisonous plants is essential. The goal of the locoweed research presented in this volume is to develop the knowledge and technologies needed to maintain our rangeland ecosystems as truly renewable resources.

TOXICOLOGY

Astragalus and *Oxytropis* Poison Livestock with Different Toxins

Lynn F. James, Kip E. Panter, Bryan L. Stegelmeier,
Michael H. Ralphs, James A. Pfister, and Dale R. Gardner

Locoweed species can contain swainsonine or other toxins that poison livestock.

Poisonous plants rank high among the major causes of economic losses to the livestock industry. Of all the poisonous plants, the *Astragalus* and the closely related *Oxytropis* genera are probably the most destructive to livestock. The taxonomy of these genera is complex and difficult even for trained plant taxonomists. These groups of plants are fascinating not only because of their complexity, but also because of their many and varied effects on animals that consume them.

Astragalus species are mostly perennial, stemmed or stemless herbs. The leaves are alternate and pinnately compound (fig. 1). Flowers are leguminous. The fruits are legume pods of various sizes and shapes. One of the most remarkable characteristics of the genus *Astragalus* is that there are hardly two species—even those closely related—that do not differ in fruit form or structure. The seeds are kidney-shaped. The seeds of some *Astragalus* species may remain viable in the soil for 40 years or even longer.

Not all *Astragalus* species are toxic. Some that are nontoxic are valuable as livestock forage. For example, livestock relish Nuttall's milkvetch *(Astragalus nuttallianus)*. The introduced species of cicer milkvetch (*Astragalus cicer*) has been used as livestock forage and also as a soil builder.

Oxytropis species are similar to *Astragalus* species except that they have erect stems and the keel of the corolla (of petals) is tipped with a sharp, erect point.

The *Astragalus* and *Oxytropis* species can be divided into three general syndromes according to the toxin they contain. *Astragalus* and *Oxytropis* species that contain swainsonine, the nitro-containing *Astragalus* species that have 3-nitropropanol or 3-nitropropionic acid, and the *Astragalus* species that accumulate selenium in toxic amounts.

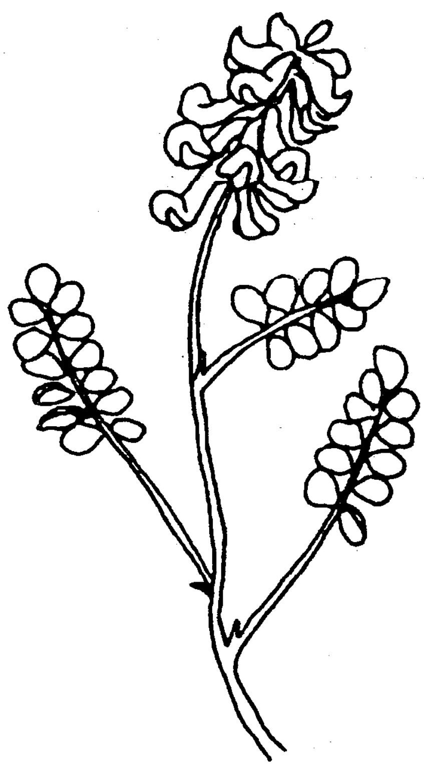


Figure 1. Locoweed leaves, which are arranged alternately on the stem and are pinnately compound.

Locoweeds

The term locoweed properly applies only to those species of the *Astragalus* and *Oxytropis* genera containing the toxic indolizidine alkaloid swainsonine in amounts that will poison animals. The term "loco" can be used as a noun to describe the plant, as a verb to describe poisoning with locoweed, or as an adjective to describe abnormal behavior (crazy). Locoweeds are destructive to livestock not only because of their wide distribution but also because of the broad variety of pathological effects and the nature of the intoxication process.

The locoweeds must be grazed over a period of weeks before the intoxication becomes apparent. By the time intoxication is recognized, the animal is in trouble and correction is difficult if not impossible. Locoweed affects animals in a number of ways. These include neurological damage, which causes the animal to behave in an abnormal fashion; emaciation or wasting; habituation (there is some question regarding this effect); abortions; skeletal birth defects; and congestive right-heart failure associated with grazing at high elevations. Animals may appear to thrive for a short time after they start to graze locoweed. But with continued grazing, they will lose weight and show other signs of poisoning.

Nitro-containing *Astragalus*

Species of this group can be found growing from western Canada throughout the western United States and into northern Mexico. Examples include red-stemmed peavine (*Astragalus emoryanus*) in New Mexico, Texas, and Mexico; *A. tetrapterus* in Utah, Nevada, Arizona, and southern Oregon; and timber milkvetch (*A. miser*) and *A. canadensis* in the western United States and Canada. There are more than 250 species in this group.

These toxic plants contain the glycosides of 3-nitropropanol and 3-nitropropionic acid. Animals poisoned by these plants develop degenerative lesions of the spinal cord and emphysema. Sheep, cattle, and horses are all sensitive to poisoning by these plants. Signs of poisoning include weakness, knuckling at hocks, goose stepping (interference of hind limbs), respiratory distress, cyanosis, sudden collapse, and death. Temporary blindness may occur. Wasting occurs with prolonged grazing. Death occurs from both acute (one large dose) and chronic (multiple doses over time) intoxications.

Selenium-accumulating *Astragalus*

Selenium in certain soils may be taken up by plants in amounts that render them toxic to grazing animals. Certain species (about 24) of *Astragalus* accumulate relatively large amounts of selenium. These include plants such as two-grooved milkvetch (*A. bisulcatus*) and Patterson's milkvetch (*A. pattersonii*). They are often called indicator plants and can be used to identify areas where selenium poisoning may be a problem. Certain forage grasses and desirable shrubs that grow in these areas may accumulate sufficient selenium to make them toxic. Poisoning of livestock is usually associated with the selenium-accumulating grasses. Some of the selenium-accumulating *Astragalus* also contain low swainsonine levels. Selenium poisoning is a problem primarily west of the Mississippi River.

Lynn F. James is the research leader, Kip E. Panter is a research animal scientist, Bryan L. Stegelmeier is a veterinary pathologist, Michael H. Ralphs and James A. Pfister are rangeland scientists and Dale R. Gardner is a chemist, all at USDA's Agricultural Research Service, Poisonous Plant Research Laboratory in Logan, Utah.

Defining the Chemistry and Biochemistry of Swainsonine

Russell J. Molyneux

Understanding locoweed's major toxic component and its effects on livestock

Locoweed's toxic component is a natural constituent of the plant named swainsonine. The compound was first discovered in the "poison peas" (*Swainsona* species) of Australia but has now been found in the locoweeds (*Astragalus* and *Oxytropis* species) of North America and other parts of the world, including South America and regions of China. It also is present in some members of the morning-glory family (*Ipomoea* species), which are poisonous to sheep and goats in southern Africa and Australia. The signs of poisoning are quite similar in animals that consume these plants.

Not all species of *Astragalus* and *Oxytropis* contain swainsonine, but it occurs in all of those that typically have been known as locoweeds (spotted loco, woolly locoweed, and white locoweed). Although the toxin content of locoweeds is not very high—generally less than 0.2% of the plant's dry weight—it appears to be highest in the flowers and seeds. However, because of its exceptional potency, it has been calculated that levels greater than 0.001% can cause poisoning if the plant is consumed over a sufficient time period. None of the above-ground parts of the plant are free of the toxin and even plants dead as long as two years retain enough of the toxin to cause locoism. An estimate of the potential hazard to livestock can be made by chemical analysis of a plant sample for swainsonine's presence.

The chemical structure of swainsonine is not complex and is quite similar to simple sugars, such as mannose and glucose, which it appears to mimic (fig. 1). As a result of this imitation, it stops the action of the enzyme α-mannosidase, which is essential for the proper functioning of all animal cells. This enzyme trims sugar molecules from complex molecules known as glycoproteins (sugar-proteins) within the cell. Once the correct number of sugars have been trimmed off, the smaller molecules can be released from the cell to serve the functions (e.g. digestion) for which they have been prepared. Failure of the trimming process results in an increase in the number of complex molecules being retained within the cell, until the cell can no longer contain them and bursts open. This

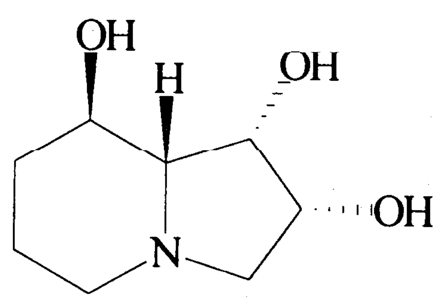


Figure 1. The chemical structure of swainsonine.

has been described as a “vapor-lock” of the cell’s production lines. After a sufficient number of cells have been damaged, the signs of poisoning appear in the animal. Because all cells depend on proper functioning of α-mannosidase, many different organs can be damaged, including the brain, heart, and reproductive and digestive systems. The particular organs affected and signs of poisoning depend on the amount of swainsonine consumed and the exposure period, as well as external factors such as nutritional status, grazing altitude, and pregnancy.

Swainsonine is very water-soluble and therefore distributes rapidly to many parts of the body. It also is rapidly excreted, primarily in the urine. But in lactating animals, a portion of it is transferred to the milk, so that nursing calves or lambs can become “locoed.” This fast excretion rate suggests that occasional locoweed consumption for short periods is unlikely to have serious adverse effects. But continuous consumption, even at relatively low levels, generally results in typical signs of locoweed poisoning. Therefore, it is important to remove animals from locoweed-infested land as soon as they are observed grazing the plant.

Russell J. Molyneux is a research chemist at USDA’s Agricultural Research Service, Western Regional Research Center in Albany, Calif.

How Locoweed Poisoning Develops and Progresses

Bryan L. Stegelmeier, Lynn F. James, Kip E. Panter, Michael H. Ralphs, Dale R. Gardner, and James A. Pfister

A summary of the development and changes caused by locoweed poisoning, current diagnostic techniques to identify poisoned animals, and information concerning locoweed toxin metabolism and excretion.

Locoweed poisoning or "locoism" results when animals ingest locoweed for several weeks. North American species that commonly poison livestock include spotted locoweed, woolly locoweed, Wooton locoweed, white locoweed, and Lambert's locoweed (*Astragalus lentiginosus, A. mollissimus, A. wootoni, O. sericea,* and *O. lambertii)* (fig. 1). These locoweeds are legume, pealike plants that are found throughout the western United States and in many parts of the world. They often grow in the early spring and late fall when other green feeds are not available. Most locoweed species are palatable and readily eaten by livestock and wildlife. Generally, the amount eaten is in proportion to locoweed availability compared with other green forages. Locoweeds remain toxic throughout the season and even the dry stalks of dying plants are poisonous.

Locoweed poisoning has an insidious onset with signs of poisoning not becoming apparent until the animal has grazed the plant for several weeks. Clinically, locoweed intoxication is characterized by depression, neurologic deficits, loss of muscular control, nervousness (especially when stressed), dull hair coat, emaciation, decreased libido, infertility, abortion, water belly (hydrops amnii), cardiovascular disease, and death.

Generally, there are no visible lesions of locoism on the animal. However, intoxication results in characteristic microscopic lesions that are described as vacuolar degeneration of neurons (fig. 2) and other parenchymatous cells. These lesions develop within 4 or 5 days after animals begin consuming locoweed. Most changes resolve in several days if consumption is discontinued. However, many neuronal lesions are not reversible as certain neurons die easily. These permanent neurologic

Figure 1. Locoweed (*Astragalus lentiginosus*).

changes can result in behavioral and functional deficits that make the value of any previously poisoned animal questionable. Additional research is needed to determine how long animals can be poisoned without developing permanent neurologic lesions and to better understand the development of these permanent secondary effects.

The diagnosis of locoweed poisoning is currently made by documenting exposure to the plant and identifying the characteristic clinical and pathologic changes of poisoning. Recently, diagnostic tests using serum from living poisoned animals have been developed.

The locoweed toxin has been identified as swainsonine, a polyhydroxy-alkaloid (with some sugar-like properties) that is a potent inhibitor of several enzymes called mannosidases. One inhibited enzyme is lysosomal α-mannosidase that degrades unneeded or damaged oligosaccharides and glycoproteins. Mannosidase inhibition results in accumulations of incompletely processed compounds in cellular vacuoles (vacuolar degeneration). This process resembles cellular constipation as the cells cannot metabolize or excrete waste material. Similar vacuolation caused by genetically abnormal lysosomal α-mannosidase is seen in genetic mannosidosis of humans, Angus cattle, and cats. Swainsonine also inhibits mannosidase II, an enzyme of glycoprotein metabolism resulting in abnormal hormones, membrane receptors, and enzymes. Consequently, locoweed poisoning results in abnormal endocrine, reproductive, immune, and gastrointestinal function. All of these changes reduce animal efficiency and production and may make poisoned animals more susceptible to disease. Low swainsonine doses of short duration do not seem to be harmful, and swainsonine may be a use-

Figure 2. Photomicrograph of a vacuolated neuron from a cow poisoned on locoweed. Bar is 25 microns.

ful pharmaceutical. Swainsonine has been shown to inhibit the spread of some cancers. It also protects certain bone marrow cells from the effects of other cancer treatments.

The locoweed toxin, swainsonine, is very water soluble. It is absorbed rapidly from the gastrointestinal tract and is quickly excreted in the urine, milk, and feces. The swainsonine clearance rate ($T_{1/2}$) from a chronically poisoned animal is a little less than 20 hours from the serum and 60 hours from the liver. This suggests that after a withdrawal time of 28 days (10 half lives), practically no toxin will remain in a poisoned animal. Reversal of the locoweed toxin's effects is slower. As normal proteins must be synthesized, packaged, and integrated into the correct location, it may take weeks or months for cell function to recover. Some cells never completely recover.

It also has been shown that after a certain dose, higher doses do not cause more severe disease. This suggests that once all the cellular mannosidase is inhibited, higher swainsonine doses are not directly toxic and do not cause more damage. This "threshold-like" response may be useful in formulating management plans to graze locoweed-infested ranges. Animals could be managed so that they ingest low doses that do not inhibit all cellular mannosidase. Alternatively, management could be changed so that all the animals get an extremely high dose of short duration with periods of withdrawal, so that the permanent changes of poisoning are avoided. More work is needed to define both safe doses and exposure duration.

Swainsonine also alters specific endocrine and cellular functions including the immune system. At low doses of short duration, swainsonine promotes proliferation and antibody production of some lymphocytes. Higher locoweed doses of longer duration inhibit this response and the final result of locoweed poisoning appears to be a suppressed immune system. Current research is underway to define the long-term, immunologic effects of locoweed poisoning.

In summary, locoweed poisoning is a chronic disease that develops after livestock graze certain *Astragalus* and *Oxytropis* spp. for several weeks. A diagnosis of poisoning can be made by documenting exposure to the plant, identifying the neurologic signs of poisoning, and analyzing serum for α-mannosidase activity and swainsonine. Many of the histologic lesions and loss of function seen in poisoned animals are regained shortly after locoweed consumption is discontinued. However, some of the neurologic changes are irreversible and permanent. This makes the usefulness of many working animals questionable, if they are poisoned.

Bryan L. Stegelmeier is a research veterinary pathologist, Lynn F. James is the research leader, Kip E. Panter is a reproductive toxicologist, Michael H. Ralphs and James A. Pfister are rangeland scientists, and Dale R. Gardner is a research chemist. All are at USDA's Agricultural Research Service, Poisonous Plant Research Laboratory in Logan, Utah.

Locoweeds Reduce Reproductive Performance in Livestock

Kip E. Panter, Lynn F. James, Michael H. Ralphs, Bryan L. Stegelmeier, James A. Pfister, Dale R. Gardner, and Russell J. Molyneux

Rams and bulls should not graze locoweed-infested pastures within 60 to 90 days of breeding.

Locoweeds include those plants of the *Oxytropis* or *Astragalus* genera that contain the toxic alkaloid swainsonine. Ingesting locoweeds interferes with all aspects of reproductive function in livestock. The severity of these effects is determined by the length of time and the amount of plant material animals graze. Certain reproductive parameters such as male and female breeding behavior may be affected within a few weeks. Other effects (ovarian and testicular dysfunction) may go unnoticed until weight loss and certain nervous disorders are evident. Abortion is the most obvious result of locoweed poisoning in pregnant animals. However, altered sexual behaviors, increased embryonic loss, decreased fetal development, increased neonatal loss, and abnormal mothering instinct or nursing behavior in the newborn may be just as costly, although not as obvious.

There is no 100% safe grazing period for livestock on locoweed as far as reproduction is concerned. Once animals begin to graze locoweed there are measurable changes such as an immediate increase in swainsonine in the animal's blood and an accompanying decrease in α-mannosidase activity, an enzyme that is critical in glycoprotein metabolism described in *Defining the Chemistry and Biochemistry of Swainsonine* (p. 12). Most reproductive functions are controlled by hormones that are glycoproteins. Many hormone receptors also are glycoproteins. Abnormal hormones and receptors result in both behavioral and reproductive dysfunction. Pathological changes in some reproductive organs have been reported within a few days of locoweed ingestion.

Research at USDA's Agricultural Research Service, Poisonous Plant Research Lab has demonstrated that locoweed ingested at 10 to 15% of the diet for as little as two to three weeks in cows and ewes altered the length of the estrous cycle, changed estrus behavior, reduced embryo numbers and viability, and reduced conception rates. Most reproductive effects are reversible when locoweed ingestion stops. The recovery period for some aspects like the development of sperm may be relatively long. Some neurological signs may not be reversible, resulting in progressive wasting and eventual death. By the time outward signs are obvious (20 to 30 days of ingestion), reproductive processes may already be severely compromised. Abortion in pregnant animals may occur after ingestion of locoweed for 20 to 30 days. Locoweed is toxic to fetuses, causing almost immediate changes in the fetal heart function. Livestock ingesting locoweed early in pregnancy may resorb or abort the fetus without obvious signs. Increased numbers of open cows or ewes may be all that ranchers observe.

Ranchers have reported significant reproductive losses in cow-calf operations from cows grazing locoweed. Therefore, we fed four mature cows white locoweed at 20% of their diet for 30 days during the estrous cycle to determine the effects of locoweed on cycling cows. The estrous cycle length was increased (fig. 1) in all cows and conception was de-

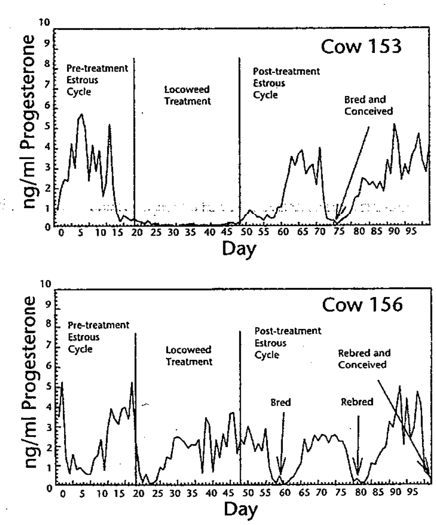


Figure 1. Progesterone profiles in two cows fed white locoweed showing extended estrous cycles. Extended follicular phase (41 days; low progesterone) in cow 153 and extended luteal phase (35 days; high progesterone) in cow 156. Both cows showed relatively normal estrous cycles soon after locoweed feeding stopped, but cow 156 bred three times before conceiving.

layed one to three estrous cycles. Serum progesterone is a good indicator of normal estrous cycle activity. Once cows conceived, pregnancy progressed normally until seven months gestation when two of the four cows were fed locoweed again for 30 days. One cow aborted one week after locoweed feeding was stopped. Cycling heifers were fed white locoweed at low, medium, and high doses representing approximately 3, 10, and 30% of the diet for 42 days. Those heifers fed the high doses of locoweed had severe changes in ovarian function by day 20, which persisted 15 to 20 days after we stopped feeding them locoweed. By day 42 after locoweed feeding stopped, ovarian function had returned to normal.

Experiments on young rams fed locoweed 60 to 70 days showed that breeding behavior and libido were altered by 20 to 30 days. Semen quality was not changed until 50 to 60 days, when numbers of abnormal sperm increased and motility decreased. While semen parameters returned to normal by 60 to 70 days after locoweed feeding stopped, neurological dysfunction persisted and eventually progressed to wasting, emaciation, and the need to euthanize six of nine rams. Therefore, we recommend that breeding rams and bulls be maintained on locoweed-free pastures and not be allowed access to locoweed within 60 to 90 days of breeding.

Other conditions caused by locoweed that may indirectly contribute to reduced reproductive performance include emaciation, abnormal breeding behavior, lack of coordination, delayed puberty, abnormal mothering instinct soon after birth, reduced nursing instinct in newborns, reduced lactation, lengthened calving intervals from year to year, and reduced growth rates in offspring.

Kip E. Panter is a research animal scientist, Lynn F. James is the research leader, Michael H. Ralphs is a rangeland scientist, Bryan L. Stegelmeier is a veterinary pathologist, James A. Pfister is a rangeland scientist, and Dale R. Gardner is a research chemist, all at USDA's Agricultural Research Service, Poisonous Plant Research Laboratory, in Logan, Utah. Russell J. Molyneux is a research chemist at USDA's Agricultural Research Service, Western Regional Research Center in Albany, Calif.

Grazing Locoweed Can Increase Incidence of Congestive Right-Heart Failure

Lynn F. James, Kip E. Panter, Bryan L. Stegelmeier,
Michael H. Ralphs, James A. Pfister, and Dale R. Gardner

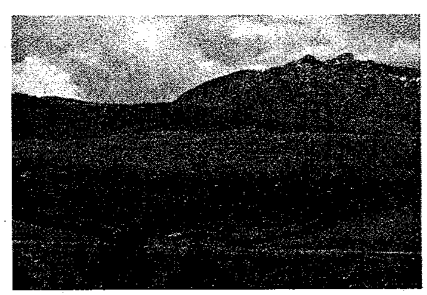
Consumption of locoweed at elevations above 7,000 feet increases incidence of congestive right-heart failure.

In cattle, congestive right-heart failure (CRHF) associated with living at high elevations (above 7,000 feet) is commonly referred to as "high mountain disease." The cause of this condition is an hypoxic-induced pulmonary hypertension associated with the reduced oxygen found at high elevations. The incidence of the disease in Wyoming and Colorado varies from 0.5 to 2%, annually. The higher the elevation, the higher the incidence. As elevations increase, the time required to develop hypoxic-induced pulmonary hypertension and, subsequently, the time to produce heart failure and signs of the disease decreases. Chronic congestive heart failure can result from a number of causes, which include traumatic pericarditis, parasitism, chronic anemia, valvular endocarditis, pneumonia, and any condition that causes a work overload on the heart's right ventricle. Cattle and especially calves grazing locoweeds at high elevations have an increased incidence of high mountain disease. The incidence approaches 100% if cattle are left to graze on locoweed more than 45 days.

CRHF has been produced by feeding the locoweed toxin, swainsonine, to cattle living at high elevations (10,000 ft). Swainsonine is highly soluble in water and is excreted in the cow's milk. Calves nursing cows that are grazing locoweed can develop CRHF. Calves can get an increased dose of the toxin by nursing an infected cow and grazing the plant. After eating locoweed for only a few days, calves become sensitive to exercise, showing weakness and reluctance to walk. Cold and fluctuating temperatures seem to enhance the development of CRHF in cattle grazing locoweed-infested ranges at high elevations. Pneumonia likewise will predispose calves at high elevations to CRHF.

Locoweed poisoning results when cattle graze white locoweed over a period of several weeks. Clinical signs of poisoning include depression; rough, dry hair coat; dull, lusterless eyes; and excitement when placed under stress. No outstanding large lesions are seen, but there are microscopic lesions of neurovisceral cytoplasmic vacuolation. Emaciation, abortion, birth defects, and interference with other reproductive processes also have been associated with locoweed poisoning. No association between CRHF and locoweed intoxication has been found at lower elevations.

The clinical signs and lesions associated with high mountain disease include dry hair coat, weakness, visible jugular pulse, right-ventricular hypertrophy and dilation, subcutaneous edema ascites, hydrothorax, chronic passive congestion of the liver, and hypervolemia with hemodilution. In advanced cases, death follows slight exertion. Medial thickening with luminal restriction of the small pulmonary arteries and arterioles develops and becomes a prominent histological feature of the condition.



Clinical signs in calves developing CRHF when grazing locoweed at high elevations are not typical of locoweed poisoning observed under usual field conditions at low altitude or as recorded in the literature. The signs of CRHF enhanced by the grazing of locoweed are similar to those seen in the typical right-heart failure condition. The clinical signs include dry nose; rough, dry hair coat; depression; dark fluid diarrhea; edema (accumulation of fluid) under the jaw, brisket, and underline; labored respiration; visible jugular pulse; weakness; and death. However, some calves appear to dehydrate rather than become edematous, but after death the gross lesions are the same. A few calves first develop the edema and then appear to become dehydrated. In some calves, the skin along the sides of the jaw becomes tight and the hairs stand erect. These calves become ill and die in a short time. Gross and microscopic lesions are the same as those observed in calves showing the more typical signs of CRHF.

At high elevations, pathologic changes of CRHF in calves fed locoweed are similar in right-heart failure to those not fed locoweed. The gross changes include right ventricular dilation and hypertrophy, subcutaneous edema, ascites, hydrothorax, profuse fluid diarrhea, and chronic passive congestion of the liver. The heart has a rounded contour due to the dilation and hypertrophy. In advanced cases, the lungs have varying amounts of atelectasis or consolidation. Microscopic lesions reflect congestive heart failure and the neurovisceral vacuolation characteristic of locoweed poisoning.

Fetal lambs from ewes fed spotted locoweed (*Astragalus lentiginosus*) during days 60 to 90 of gestation have an enlarged right ventricle of the heart and edema about the neck area. Fetal lambs from ewes fed locoweed also have lesions of locoweed poisoning. The changes observed in these fetal lambs are reminiscent of calves consuming locoweed at high elevations. The changes may be related to the CRHF observed in calves fed locoweed at high elevations. Locoweed also can cause hydrops amnii (an accumulation of fluid in the placenta) in cattle grazing locoweed. Locoweed poisoning lesions are found in the fetal calves of these cows. These calves have large fluid-filled abdominal cavities. This could be the result of heart or other vascular degeneration related to consuming the locoweed toxin.

It has been found that the CRHF in calves whose mothers are grazing on locoweed-infested ranges at high elevations can largely be reversed by moving them off the locoweed and to lower elevations within 40 days of starting to graze locoweed.

Lynn F. James is the research leader, Kip E. Panter is a research animal scientist, Bryan L. Stegelmeier is a veterinary pathologist, Michael H. Ralphs and James A. Pfister are rangeland scientists, and Dale R. Gardner is a chemist, all at USDA's Agricultural Research Service, Poisonous Plant Research Laboratory in Logan, Utah.

Locoweed Alters Ewe and Lamb Behavior

James A. Pfister, Bryan L. Stegelmeier, Kip E. Panter,
Lynn F. James, Michael H. Ralphs, and Dale R. Gardner

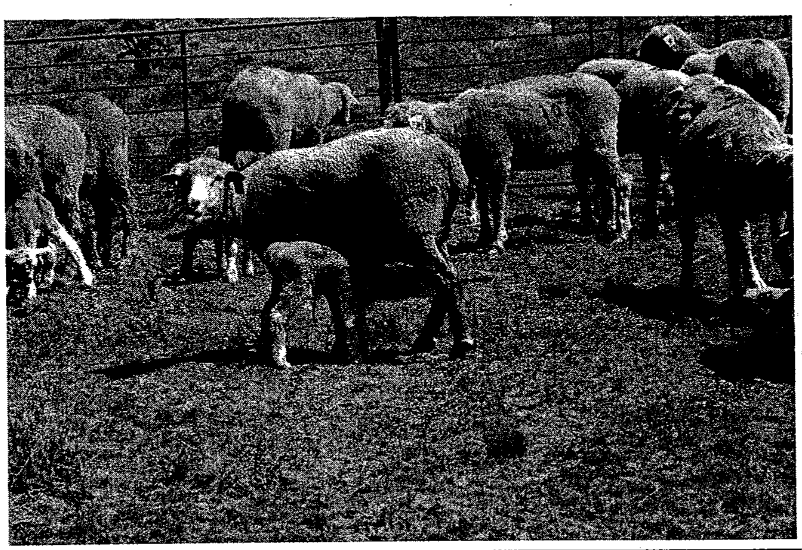
Eating locoweed can interfere with ewe-lamb bonding.

Behavioral studies were conducted several years ago to examine some of the possible effects of locoweed on livestock behavior. The first studies focused on the effects of locoweed on ewe-lamb bonding at birth and on newborn lamb behavior shortly after birth.

Thirty ewes were hand-mated to lamb within a certain time period. When the ewes were pregnant for 100 days, they were divided into treatment and control groups. The locoweed treatment group received white locoweed for 30 days as a 10% locoweed pellet (90% alfalfa hay). Two ewes aborted in 15 to 30 days; the other ewes lambed normally.

The locoweed-treated ewes did not bond normally with their lambs. The poisoned ewes were nervous and circled their lambs excessively, making nursing virtually impossible. The lambs from poisoned ewes were developmentally delayed at birth in every measurement compared to normal lambs. They were slow to stand, slow to seek the udder, and were unable to nurse without human assistance. In a behavioral test battery, these lambs were less mobile than control lambs and had difficulty recognizing their dam from another ewe. Poisoned ewes did not have difficulty recognizing their own lamb from a strange lamb. The lambs poisoned during gestation recovered much of their ability to function within 7 to 10 days. When retested a few months later, lambs from poisoned ewes were indistinguishable from normal lambs.

We also studied if lambs from ewes eating locoweed would eat more locoweed than lambs from ewes that would not eat locoweed. Three groups of ewes were conditioned: loco-eaters, loco-avoiders, and those with no experience with locoweed. Lambs were then exposed to locoweed with their mothers and later tested alone. A fourth treatment group



included orphan lambs with no maternal interaction. Lambs from all the groups ate locoweed when tested, and mother's experience had only a slight impact on the lamb's eating behavior. Short-term maternal influence apparently was not sufficient to teach lambs to eat locoweed compared to control lambs. Nonetheless, other studies we have done suggest that even limited consumption of locoweed by young animals may set the stage for increased locoweed consumption later in life.

Cyclic or "on-off" grazing programs have been suggested as a means of limiting how poisoned livestock become when grazing locoweed-infested pastures combined with locoweed-free pastures. We examined the behavioral effects of intermittent locoweed consumption in sheep. Sheep were fed a 10% locoweed pellet for 3- to 5-week periods with 3- to 5-week recovery periods for 22 weeks.

Sheep showed evidence of poisoning after the initial, 4-week "on" locoweed period and never fully recovered behaviorally even though the initial dose of locoweed was low. Some sheep were sacrificed at the end of locoweed feeding and showed brain lesions, whereas other sheep were allowed to recover for 5 weeks then euthanized. After five weeks recovery ("off" locoweed), sheep continued to show persistent behavioral signs of locoweed poisoning even though brain lesions had largely resolved. These findings suggest that even a 4-week low dose of locoweed may be excessive and could permanently jeopardize animal health.

James A. Pfister is a rangeland scientist, Bryan L. Stegelmeier is a veterinary pathologist. Kip E. Panter is a reproductive toxicologist, Lynn F. James is the research leader, Michael H. Ralphs is a rangeland scientist, and Dale R. Gardner is a research chemist, all with USDA's Agricultural Research Center, Poisonous Plant Research Laboratory in Logan, Utah.

Low-Level Locoweed Consumption Alters Blood Chemistry in Sheep

Joshua B. Taylor and James R. Strickland

Finding a tolerable locoweed consumption level for sheep could help ranchers manage locoweed-infested pastures.

Locoweeds are common legume plants found on rangelands in the western United States. These plants, when consumed in adequate amounts, result in a toxicity syndrome known as "locoism," which is characterized by depression, emaciation, abortion, hyperexcitability, lack of coordination, decreased feed intake, and rough hair coats. The toxin apparently responsible for this syndrome is swainsonine.

Large amounts of data have been published concerning locoism. However, the vast majority of the data has been concerned with locoweed consumption levels that are high enough to cause clinical (visual) locoism. This research has allowed the identification of visual symptoms and some subclinical indications (require laboratory tests to identify) of locoism. These include alterations in blood chemistry values, such as increased alkaline phosphatase activity. In addition, most of the studies to date have resulted in blood swainsonine concentrations of 150 ng/mL or greater. As such, the issue of low-level locoweed consumption associated with swainsonine levels of <150 ng/mL has not been adequately addressed.

Additionally, most of the research to date has focused on locoweed consumption in sheep or cattle consuming diets adequate in nutritional content. However, range forage availability during periods of locoweed prevalence may not be adequate to fully meet the animal's nutritional requirements. Therefore, we have conducted experiments designed to address the issues of low-level locoweed consumption and nutrient restriction on range animal health.

Our objective is to define a level of locoweed consumption in sheep eating a nutrient-restrictive diet—animals receive only 65% of their energy requirements—that does not cause clinical or subclinical locoism. Defining a tolerable locoweed consumption level will allow us to make more definitive recommendations concerning the use of locoweed-infested rangelands.

To address our objective, we fed 28 sheep energy-restricted diets containing varying levels of swainsonine (supplied as locoweed) for 28 days. Because swainsonine content varies greatly among different locoweeds, we fed locoweed on the basis of its swainsonine content. Therefore, our findings are discussed in relation to the levels of swainsonine in the plant and in the animal's blood. This is necessary if we wish to define a locoweed consumption level that can be tolerated by a grazing animal. Recovery of sheep from locoweed's effects was monitored for an additional 21 days following removal from locoweed. We collected blood (serum) samples 24 hours after feeding and performed immune function tests weekly to assess the dose-response effects of locoweed (swainsonine).

The consumption of locoweed by sheep in our trial did not appear to adversely affect the lymphocyte component (a type of white blood cells including T-cells and B-cells) of the animal's immune system. Lymphocytes are only a portion of the immune system. Thus, these findings do

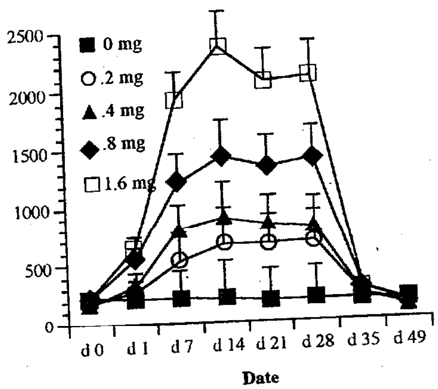


Figure 1. Effect of white locoweed consumption on ovine serum alkaline phosphate activity. Treatments (TRT) were 0, 0.2, 0.4, 0.8, and 1.6 mg swainsonine/kg body weight.

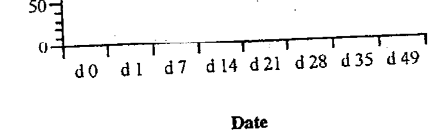


Figure 2. Effect of white locoweed consumption on ovine serum aspartat amino transferase. Treatments (TRT) were 0, 0.2, 0.4, 0.8, and 1.6 mg swainsonine/kg body weight.

not mean that locoweed does not have any adverse effects on the immune system as a whole. In fact, *in vitro* (test-tube) studies previously conducted in our laboratory (not reported here) indicate the potential for decreased function of T-cells due to swainsonine consumption.

In addition, other researchers have reported effects of locoweed or swainsonine on the immune system of cattle and sheep. Inadequate nutrition can, at least potentially, adversely affect the immune system. Therefore, the lack of an effect in this set of sheep experiments may be the result of an already compromised immune system. This may preclude the chances of detecting effects due to swainsonine on the immune system. As such, further research is needed to fully explore swainsonine's effects on the immune system of range livestock.

Analysis of serum from sheep consuming locoweed confirmed the presence of swainsonine in the blood (table 1). Taking into account the half-life of swainsonine in the blood (about 20 h), serum swainsonine levels in our experiment only approached or exceeded the serum level of swainsonine (150 ng/mL) that is known to cause clinical and subclinical locoism in the two highest dosage levels fed. We succeeded in feeding locoweed levels that induced serum levels below those previously reported. This allowed us to begin studying the effects of low-level swainsonine consumption on animal health.

Blood was analyzed for the presence of several diagnostic enzymes and nutrients. Alkaline phosphatase (fig. 1), aspartate aminotransferase (fig. 2), and lactate dehydrogenase (table 1) enzyme levels were elevated in sheep consuming locoweed. Elevations of these enzymes indicate tissue damage, including liver and kidney damage. In addition, blood iron and cholesterol levels were decreased. Reductions in serum levels of these nutrients may indicate damage to the kidney, liver, and/or gastrointestinal tract.

Although these blood chemistry values indicate that damage occurred due to locoweed consumption, there is evidence that lower locoweed consumption levels may be tolerated by the animals. For instance, alkaline phosphatase levels were only elevated in animals consuming locoweed at doses of $\geq$0.4 mg of swainsonine/kg body weight/day. Likewise, cholesterol was only reduced at 1.6 mg of swainsonine/kg body weight/day. Thus, it may be possible to define a locoweed consumption level based on swainsonine content that animals tolerate. However, this level will most likely be below the levels fed in this study. Establishing a locoweed consumption level that is safe will be useful in developing management systems for using rangelands infested with locoweed.

Table 1. The effects of white locoweed consuption (28 days) on sheep serum constituents and serum swainsonine 24 hours after feeding.

		Treatment[1]					
Serum constituents		0 mg	0.2 mg	0.4 mg	0.8 mg	1.6 mg	SE
Lactate dehydrogenase (U/L)		390.9	408.3	414.2	454.1	499.2	31.4
Iron (µg/dL)		146.8	113.5	94.5	101.9	103.8	9.6
	Day						
Cholesterol (mg/dL)	7	90.4	85.7	95.1	96.3	73.3	5.8
	14	88.4	87.7	89.1	89.6	63.8	7.0
	21	83.4	84.7	81.0	78.6	55.3	6.7
	28	80.4	79.3	73.6	76.7	60.0	5.4
Swainsonine (ng/mL)	1	ND	15.7	11.8	46.3	96.5	10.0
	7	ND	20.3	16.1	63.4	109.3	14.0
	14	ND	16.3	26.0	58.9	62.3	14.0
	21	ND	23.0	17.3	69.4	12.3	11.0
	28	ND	18.0	23.0	66.9	78.0	14.0

[1]Treatments are 0, 0.2, 0.4, 0.8, and 1.6 mg swainsonine/kg body weight. ND = not detectable.

Joshua B. Taylor is a graduate research assistant and James R. Strickland is an assistant professor of nutritional toxicology, both in the Department of Animal and Range Sciences.

Looking for Ruminant Bacteria that Can Detoxify Swainsonine

Marilee Morgan and Tammy May

Swainsonine, the toxicant in locoweeds, is an organic compound similar to a simple sugar and may be used as a food source by microorganisms found in the rumen.

Figure 1. Cattle grazing in northern New Mexico in early spring.

Legumes of the genera *Astragalus* and *Oxytropis* found in the southwestern United States are commonly referred to as locoweeds. These locoweeds often are the only forage available to grazing cattle at certain times of the year and are as nutritious as alfalfa (figs. 1 and 2). Many species of these genera contain swainsonine, the chemical believed to be responsible for locoism in grazing cattle. This chemical inhibits important enzymes involved in glycoprotein (sugar-protein) processing and results in the accumulation of these compounds in the brain, liver, and kidneys.

Animals that graze locoweed suffer from neurological effects, emaciation, reproductive disorders, and eventually, death. The rumen (multicompartment stomach) of these animals is teeming with diverse populations of microorganisms with all major bacteria groups represented. Furthermore, swainsonine is similar structurally to mannose, a simple sugar like glucose. It is not unreasonable to assume that a potential for swainsonine metabolism exists in the rumen and may only need to be stimulated.

The goal of our research is to investigate this potential in order to eliminate or decrease the concentration of swainsonine in the rumen and, therefore, reduce its effect on the animal. Improving tolerance of locoweed would eliminate revenue losses for ranchers from locoism, as well as provide sufficient forage at no extra cost.

Bovine rumen samples were collected to obtain ruminal microorganisms that could grow on the sugar mannose as a preliminary step to growing them on swainsonine. Mannose and swainsonine share similarities in their chemical structures. Swainsonine was not used directly due to its cost and lack of availability.

Several bacterial types isolated from rumen were obtained for further experiments. Two of the isolates were chosen, based on their differing cell morphologies. A cell growth experiment was performed using swainsonine by itself (100 g/ml), mannose alone (4 mg/ml) as a viability control, and swainsonine + mannose (100 g/ml + 2.4 mg/ml, respectively) to determine if an additional carbon (food) source in the form of mannose was needed for swainsonine to degrade. A control set containing no carbon source also was included.

Swainsonine concentrations were determined indirectly at the beginning and end of growth, using an enzyme assay (the α-mannosidase inhibition assay). The two bacterial isolates grew well when mannose was added, but growth on swainsonine alone was insignificant (figs. 3 and 4). Additionally, no loss of swainsonine was detected in the cultures where it was added (table 1). This experiment was repeated after several transfers using media with swainsonine as the sole carbon source to allow the microorganisms to adapt. The same results were observed (data not shown).

A previous study in our lab investigated swainsonine use by *Klebsiella* and *Pseudomonus* species, with swainsonine concentrations at 5.0, 1.0, 0.5, and 0.25 g/ml. Once more, growth was not observed for any of the swainsonine cultures (unpublished data). It is possible that adapting to swainsonine use may take longer than was allowed in these studies. Additionally, the swainsonine concentrations used may either be toxic to the organisms or unavailable because it was in such low concentration, the latter being the more probable explanation. Furthermore, the cow used as a source of inoculum for this study was not exposed to locoweed and it would be more appropriate to use ruminal fluid from an animal ingesting swainsonine. Swainsonine disappearance was not detected with the analytical method used. The α-mannosidase inhibition assay is highly variable and hard to reproduce. An alternative or parallel method of determining swainsonine content is desperately needed to continue this type of research. The present effort is to develop a reliable method of swainsonine analysis.

Figure 2. A white locoweed plant surrounded by dormant, dry foliage.

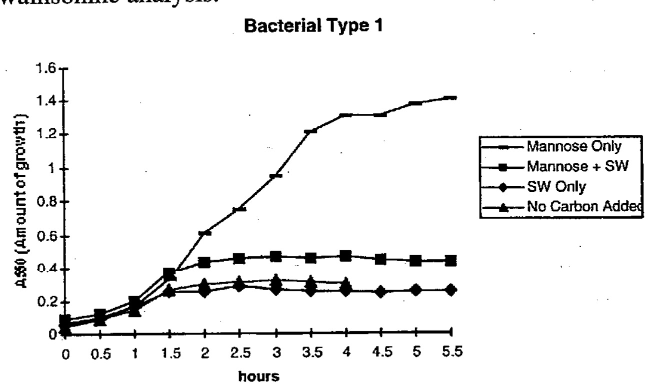


Figure 3. Absorbance measured for bacterial type 1 to determine if swainsonine will support growth.

Figure 4. Absorbance measured for bacterial type 2 to determine if swainsonine will support growth.

Marilee Morgan is a laboratory technician/research associate and Tammy May is an assistant professor of animal science, both in the Department of Animal and Range Sciences.

ECOLOGY AND PHYSIOLOGY

Describing the Common Locoweeds and Milkvetches of New Mexico

William E. Fox, Kelly W. Allred, and Eric H. Roalson

A new guide offers information on New Mexico's common locoweed and milkvetch varieties.

In the western United States, poisonous species of locoweeds and milkvetches contribute to millions of dollars in livestock losses each year. An authoritative guide has been published that describes New Mexico's 19 most common locoweeds and milkvetches (genera *Astragalus* and *Oxytropis*), including 35 different varieties. In *Guide to the Common Locoweeds and Milkvetches* (fig. 1), range managers and ranchers will find helpful information about toxins in these poisonous plants and their effects on livestock, plus techniques for controlling and managing the toxic plants. A key feature of this guide is computer software for identifying the common species in New Mexico. The guide also provides a written dichotomous key to the species. A thorough identification section provides common and scientific names, field recognition features, detailed descriptions of the plants with 87 color photographs, distribution and habitat information, and maps of each species' occurrence in New Mexico.

A Guide to the Common Locoweeds and Milkvetches of New Mexico, Circular No. 557, is available from the department of Agricultural Communications, College of Agriculture and Home Economics, New Mexico State University, Las Cruces, NM 88003, (505) 646-2701. The cost is $15.

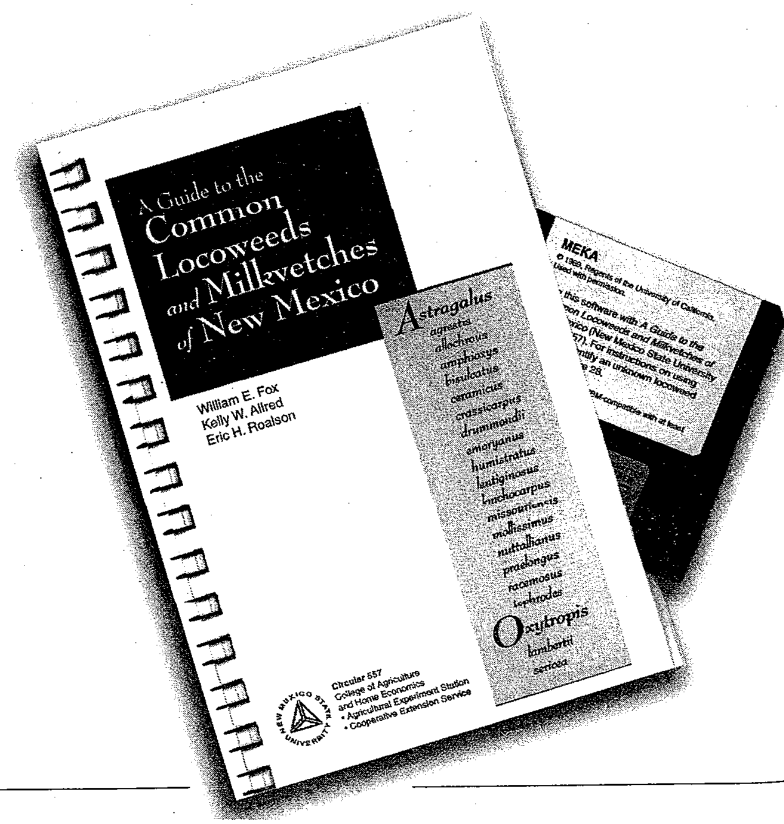
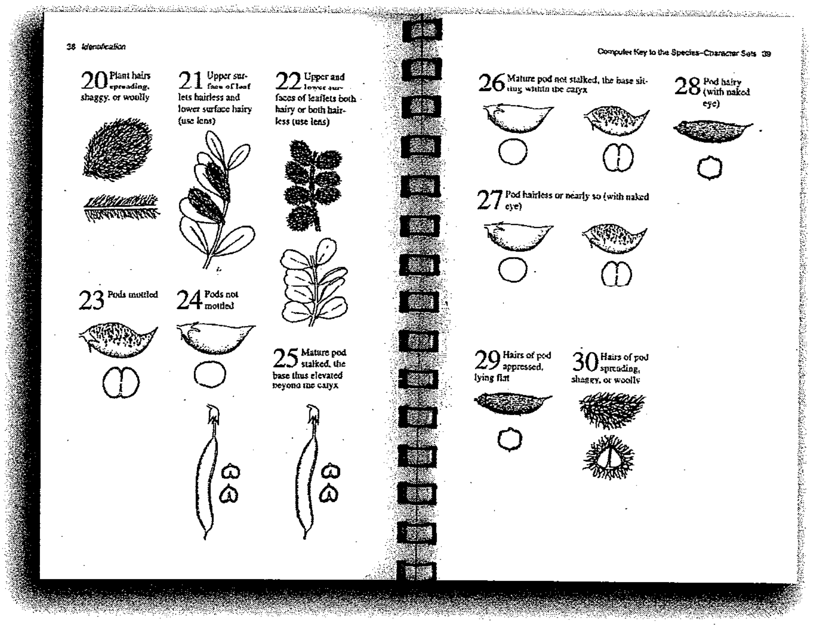
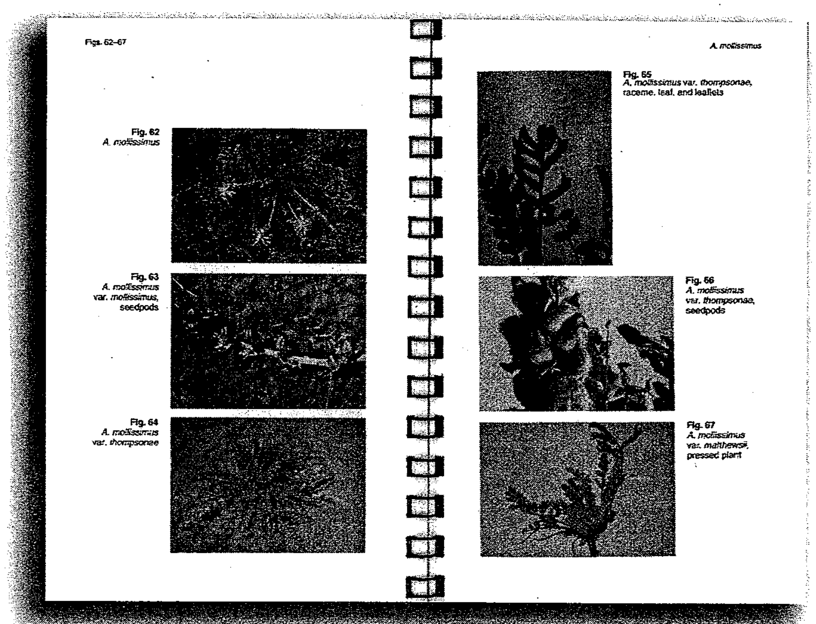


Figure 1. The 95-page *Guide to the Common Locoweeds and Milkvetches.*





William E. Fox has a master of science degree in range science from NMSU. He is completing a doctoral degree at Texas A&M University. Kelly W. Allred, professor of range plant taxonomy, is curator of NMSU's Range Science Herbarium. Eric H. Roalson has a master of science degree in range science from NMSU. He is completing a doctoral degree at Rancho Santa Ana Botanic Garden in California.

When Rain Falls May Affect Locoweed Density

Jared Purvines and J. David Graham

Locoweed density may depend more on spring precipitation than precipitation in other seasons.

Locoweed is an ongoing and increasing problem for ranchers in northeastern New Mexico. To develop management techniques that will lessen locoweed poisoning of livestock, it is necessary to better understand the plant itself. For example, it is important to know if locoweed plant density varies significantly from year to year and if the density depends on precipitation during different times of the year.

The purpose of this study was to determine if a correlation exists between precipitation and locoweed density. Previous studies indicate that there may be a correlation. Therefore, we studied 30 years of precipitation data from the National Oceanic and Atmospheric Administrations (NOAA) weather stations located in the northeastern New Mexico communities of Amistad, Des Moines, Pasamonte, and Springer. Ranchers from each of the subject communities completed locoweed surveys and provided their data.

Surveys were distributed randomly to ranchers with 30 or more years of ranching/grazing experience in the subject communities.

The survey assessed extent of individual problems, problem years between 1964 and 1994, and grazing practices in problem years between 1964 and 1994. Participants were advised that survey data would be correlated with weather archives.

Precipitation data was analyzed by season. The winter season included December, January, and February; spring included March, April, and May; summer included June, July, and August; fall included September, October, and November. We calculated 30-year precipitation averages by season and community. For each season, we compared each year's seasonal precipitation to the 30-year, seasonal average. Deviations were expressed as a percent of departure from the average.

No correlation was found between locoweed density and summer or fall precipitation in the four communities (fig. 1). A correlation between density and winter precipitation was found. However, it was varied and inconsistent. Interestingly, there was an obvious and consistent correlation between spring precipitation and locoweed density in all four communities (fig. 2).

It is possible, then, that ranchers can expect increased locoweed infestations during years with above-average spring precipitation.

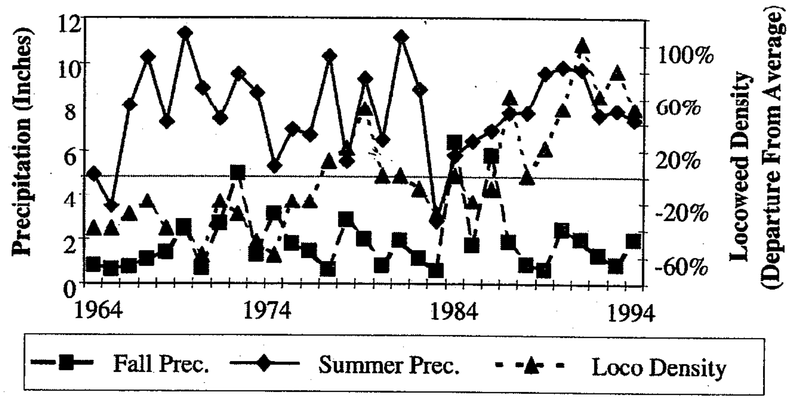


Figure 1. Fall and summer precipitation versus locoweed density.

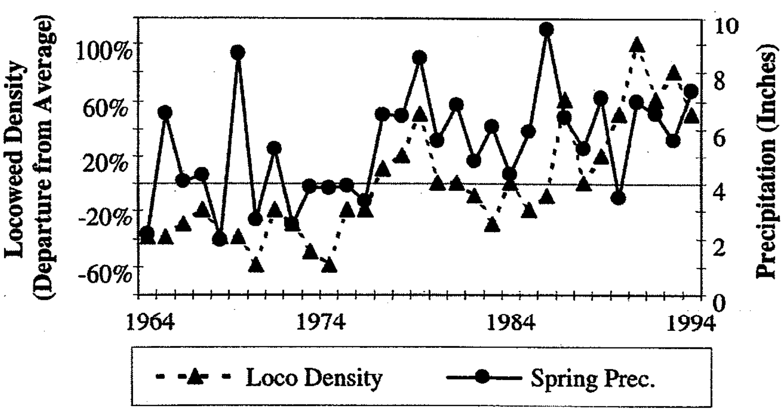


Figure 2. Spring precipitation versus locoweed density.

Jared Purvines is an agriscience student in Des Moines, N.M. at Des Moines High School. This work was a Union County 4-H science project that qualified Jared for the 1998 International Science Fair in Forth Worth, Texas.

J. David Graham is a Union County Extension agent in Clayton, N.M.

Drought-Stressed Locoweed Contains More Swainsonine

Jared Purvines and Michael H. Ralphs

Ranchers should watch for cattle grazing locoweed, even when locoweed plants are sparse and stunted during or following a drought.

Locoweed causes the most widespread poisonous plant problems in the western United States. Losses to the cattle industry in Union County, N.M. alone exceed $3 million annually. Many studies are underway to find an acceptable and cost-effective way to control or manage locoweed-infested rangeland. By observing seasonal precipitation, we might be able to make some predictions about locoweed's growth.

Previous studies have shown a direct correlation between locoweed density and spring precipitation. Seasonal precipitation was compared with data collected from locoweed surveys provided by northeastern New Mexico ranchers.

We conducted this experiment to determine the effects of spring and winter precipitation and simulated grazing on locoweed's growth, plant mortality, and toxicity.

Precipitation data came from the Capulin Volcano National Monument near Capulin, N.M. Plant data came from locoweed plants growing within a fenced test plot, located near Capulin. We assigned 40 plants serial numbers and paired them with plants of similar size. To approximate grazing, one plant from each pair was clipped, and one was left as the control. Plants were clipped on an annual basis for three years.

During June of each year, we measured the plants. We sent clipped plants to NMSU's Clayton Livestock Research Center, where they were dried and weighed. Dried and ground samples were tested for swainsonine content at New Mexico State University's animal nutrition laboratory. Swainsonine is an alkaloid identified as the toxic agent in locoweed.

We found that increased spring and winter precipitation increases plant growth, with spring precipitation having more impact than winter precipitation. Severe winter weather and spring drought in 1996 greatly increased plant death, even though the summer and fall precipitation following the drought was normal. Clipping had no significant impact on plant growth or mortality (fig. 1).

Plants that experienced below-normal winter and spring precipitation in 1996 had an increased swainsonine content (fig. 2). In this experiment, the drought-stressed plants had a 37% higher swainsonine content than the plants that received normal precipitation. This means that drought-stressed plants, although smaller, are more toxic than the larger, lush plants. If, as commonly believed, livestock graze more locoweed during a drought, damage to livestock will increase.

This research indicates that following winter and/or spring drought, ranchers should be especially vigilant in observing if their livestock are consuming locoweed. If so, they should start cost-effective management changes to lessen locoweed consumption.

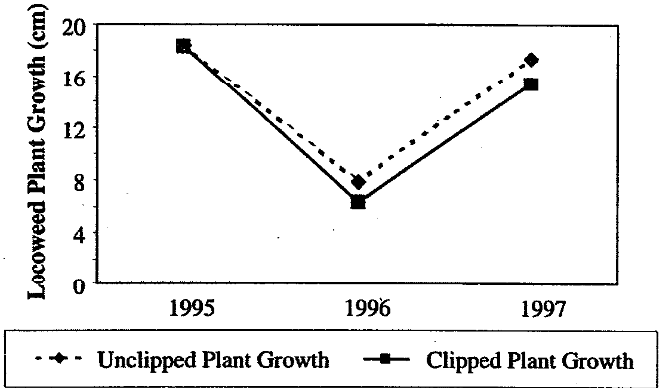


Figure 1. Locoweed growth rate: clipped versus unclipped.

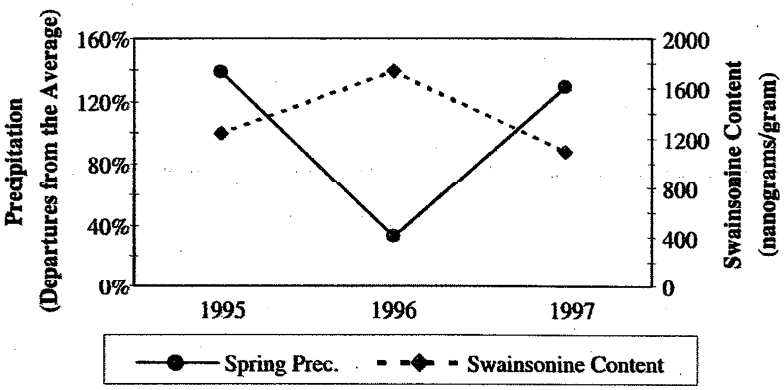


Figure 2. Swainsonine content versus spring precipitation.

Jared Purvines is an agriscience student at Des Moines High School in Des Moines, N.M. This work was a Union County 4-H science project that qualified Jared for the 1998 International Science Fair in Fort Worth, Texas. Michael H. Ralphs is a rangeland scientist at USDA's Agricultural Research Service, Poisonous Plant Research Laboratory in Logan, Utah.

Walshia miscecolorella Caterpillars May Alter Swainsonine Levels in White Locoweed

Marie C. Campanella, Tracy M. Sterling, and David C. Thompson

Finding out how caterpillars affect swainsonine in white locoweed could have an impact on biological control of the weed.

Locoweeds are known to cause the chronic, neurological disease locoism in livestock. Locoism is thought to be induced by the secondary plant product swainsonine, a toxic alkaloid in locoweed plants. Secondary plant products are chemicals produced by plants, which have no known purpose in the plant's primary metabolism, but are apparently important to the plant's responses to its environment. Symptoms of locoism in livestock include a desire to consume only locoweed, an impairment of the nervous system, and higher abortion rates. White locoweed is a common species of locoweed growing on rangelands across the western United States and is the most abundant and destructive locoweed in New Mexico. Because of the weed's toxic effects to livestock, methods to control locoweed, including biological control, are being tested.

The small caterpillar, *Walshia miscecolorella*, and moth (figs. 1 and 2) are native to New Mexico rangelands. These caterpillars feed on the crown area and lateral roots of white locoweed. A large number of caterpillars feeding on the roots will severely damage the plant, making the caterpillars potential biological control agents. But a common response by many plants to herbivory or insect-feeding is an increase in the concentration of secondary plant compounds like swainsonine. Thus, the value of these caterpillars as biological control agents would be reduced if swainsonine concentration increases in white locoweed when fed upon by caterpillars. Therefore, at several locations in Colfax County, N.M.,

Figure 2. The caterpillar, *Walshia miscecolorella,* feeding on a white locoweed leaf.

Figure 1. The adult moth, *Walshia miscecolorella,* on a white locoweed leaf.

we compared the swainsonine levels of white locoweed plants infested with caterpillars to plants that were free of caterpillars .

White locoweed's swainsonine content varied among the collection sites (table 1). This means swainsonine content is probably dependent on the environmental conditions under which the plant grows. In addition, white locoweed plants containing caterpillars had about 33% more swainsonine than plants with no caterpillars (table 2). This could mean either higher swainsonine concentrations attracted the caterpillars to feed on these plants or the insect-feeding caused greater swainsonine production in the plants. Further testing is needed to determine if caterpillars are actually inducing higher levels of swainsonine, or if they are just attracted to those plants containing the higher levels. The answers to these questions should have important implications for white locoweed management using biological control.

Table 1. Swainsonine concentrations for plants collected at different sites.

Location in Colfax County	Swainsonine content
	(µg swainsonine/g fresh weight)
4	1284 ± 115
3	1264 ± 209
1	976 ± 205
5	883 ± 117
2	745 ± 139

Figure 3. Collection sites in Colfax County, N.M.

Table 2. Swainsonine concentrations for plants with and without caterpillars.

Caterpillars feeding on roots	Swainsonine content
	(µg swainsonine/g fresh weight)
yes	1231
no	830

Marie C. Campanella is a research assistant, Tracy M. Sterling is an associate professor of weed science, and David C. Thompson is an associate professor of entomology, all in the Department of Entomology, Plant Pathology, and Weed Science.

MANAGEMENT

Biological

Chemical

Grazing

Common Locoweed-Feeding Insects

David C. Thompson

What is that insect feeding on my locoweed?

A variety of insects are associated with both white and woolly locoweed. Many of these insects are incidental, only visiting the plants to collect nectar or to find a protected place to stay for awhile. I receive many calls from people who want to know the identification of insects found "feeding" on their locoweed. The following are pictures and basic descriptions of the most important insects attacking locoweeds in New Mexico.

Four-lined locoweed weevil (*Cleonidius trivittatus*) is the most important insect to attack woolly locoweed. The adults (fig. 1a) are grayish to brownish and about 1/2 to 1 inch long with 4 dark stripes down their backs. They feed on the leaves and stems of locoweed; however, the immature larvae cause most of the damage. Larvae (fig. 1b) are 1/8 to 3/4 inch long, legless, cream colored, "C" shaped with a brown head and jaws. They can be found feeding on the outside or inside of the root of woolly locoweed. Weevil larvae construct a chamber inside the root or in the soil adjacent to the root in which they pupate (fig 1c). Adults lay individual, bright yellow eggs (fig. 1d) in the late fall through early spring, that are commonly covered with chewed locoweed leaves. Feeding by two weevil larvae killed most sizes of woolly locoweed in our research plots.

Locoweed root-borer moth (*Walshia miscolorella*) commonly attacks both white and woolly locoweed. Adult moths (fig. 2a) are small, only about 1/2 inch long, "cigar-shaped" with long, narrow wings that have bands of white, black, dark brown, yellowish brown and reddish brown. Moths can be seen flying around the plants at dusk or when the plants are disturbed. The larvae (fig. 2b) have six legs near the head and several pairs of short, stubby legs (called prolegs) toward the rear of the caterpillar. They are white with a light-brown head. A dark spot is usually visible just beyond the middle of the abdomen when looking down on the top of the caterpillar. We have recorded as many as 25 larvae feeding on one plant, resulting in serious damage to woolly locoweed. Unfortunately, white locoweed branches just above the crown, and the caterpillars will kill individual branches. However, they rarely kill a whole plant.

Locoweed stem-boring fly (*Delia [Hylemya] lunini*) feeds on both white and woolly locoweed. The adults (fig. 3) are small (1/4 to 3/8 inch long) flies that have yellow heads and yellow stripes on the sides. The larvae or maggots are pure white with no apparent head or legs. The maggots bore into the leaflet and flower stalks, feeding inside of them as they expand. Occasionally, we find plants where almost every stalk is attacked; however, little damage other than a small decrease in seed production results.

Sitona weevil (*Sitona californicus*) is found feeding on woolly locoweed. Adults (fig. 4a) are usually solid tan or gray and are about 3/8 inch long with a distinctive "snout." They feed at night on the leaflets and newly developing stems. The larvae, which look just like little four-lined locoweed weevil larvae, feed on the outside of the tap root and lateral roots. Sitona weevils feed much further down on the roots than the other weevil and commonly spiral around the root as they feed (fig. 4b). These weevils are commonly associated with plants attacked by the four-lined locoweed weevil, and they have not been found feeding on any other plants.

Lycaenids (Lycaenidae) are small butterflies. As caterpillars, they feed on both white and woolly locoweed. We have recorded the Melissa blue (*Lycaeides melissa melissa*) feeding on white and woolly locoweed, and the Acmon blue (*Icaricia acmon*) feeding on woolly locoweed. While other species of Lycaenids have been recorded feeding on locoweeds, these are the only ones we have found. The adults (fig. 5a) are small (wingspan less than 1½ inches), blue butterflies with a series of small orange spots on the back of the hind wings. The larvae (fig. 5b) are green, ranging from 1/4 to 3/4 inch long and very difficult to see while feeding on locoweed leaves. Larvae chew small holes in the upper surface of the leaves, insert their heads, and consume the tissues that they can reach between the leaf surfaces. This results in plants with characteristic white spots (fig. 5b), many times 5 or 10 per leaflet. These insects feed on a variety of other closely related plant species.

Mealybugs (Coccoidea) are small, sucking insects that feed on the roots and crown of white and woolly locoweed. Mealybugs (fig. 6) are small (1/16 to 3/8 inch), oval shaped, and covered with a fine, whitish "powder" or wax. The insects can be found feeding individually or in large numbers (greater than 100/plant), especially on plants damaged by other insects. Many species of mealybugs are attended by ants, which protect the mealybugs and help move them from plant to plant. The ants use the mealybugs' honeydew as a food source. We know very little about the mealybugs attacking locoweed in New Mexico.

Seed weevils (Bruchidae) are small, gray, oval or egg-shaped beetles, that feed on the seed pods of white and purple locoweed. The adults are about 1/8 inch long (about the size of a locoweed seed–see fig. 7a) with wing coverings that seem to be "short," not completely covering the abdomen. They lay eggs on developing locoweed seed pods. Seed pods that are attacked have a characteristic hole near the base of each pod (fig. 7b). The weevil larvae feed inside the pod, many times destroying all seeds in a pod. Unfortunately, densities are rarely high enough to eliminate seed production.

David C. Thompson is an associate professor of entomology in the Department of Entomology, Plant Pathology, and Weed Science.

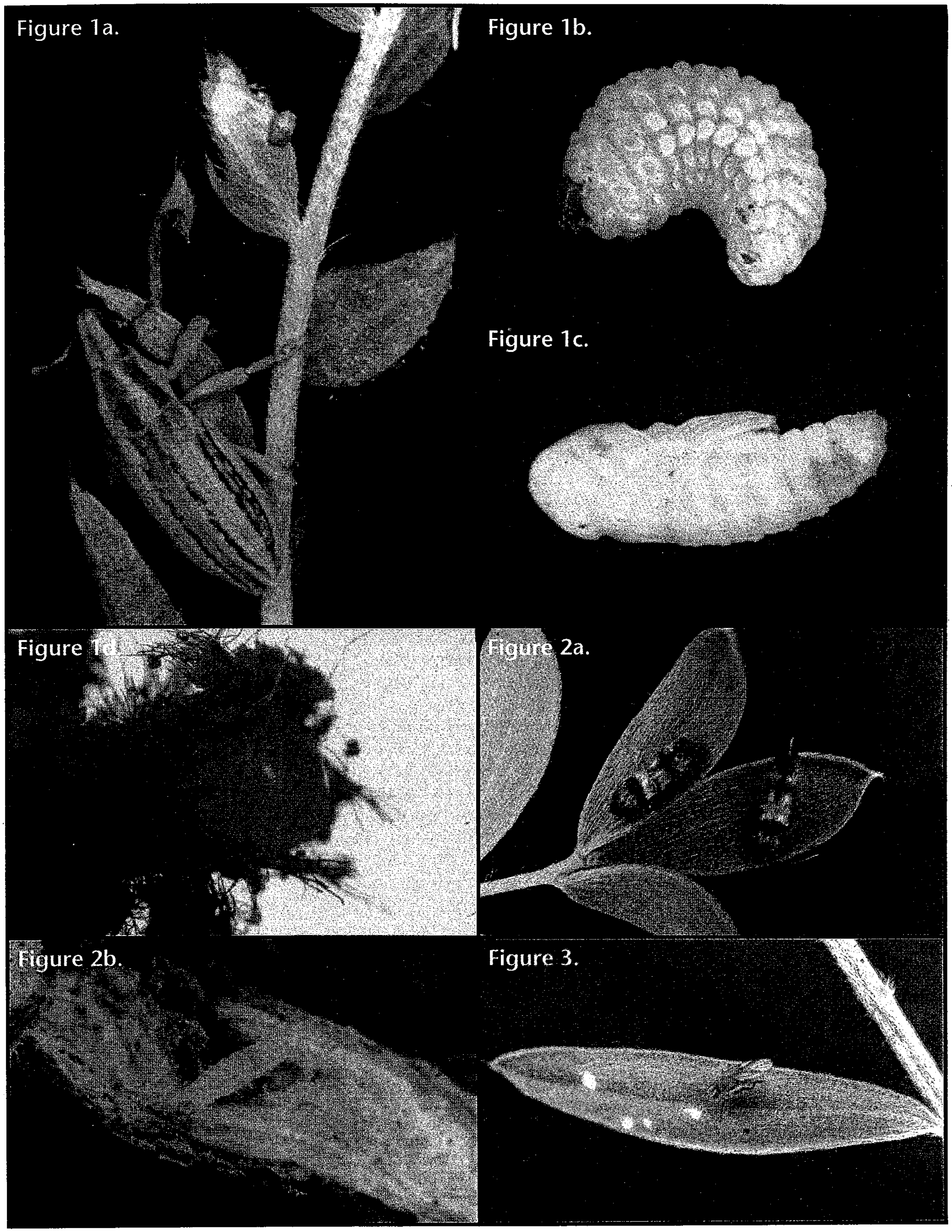


Figure 1a.
Figure 1b.
Figure 1c.
Figure 1d.
Figure 2a.
Figure 2b.
Figure 3.

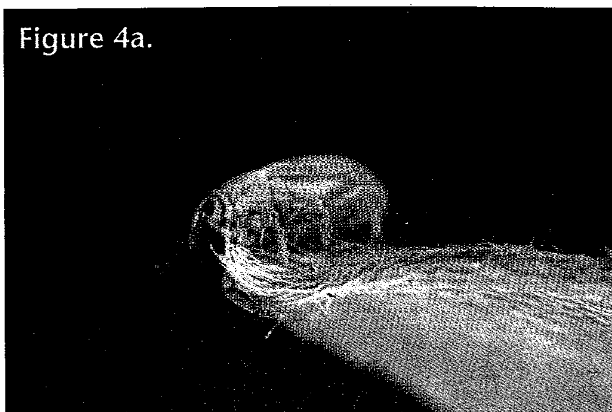


Figure 4a.

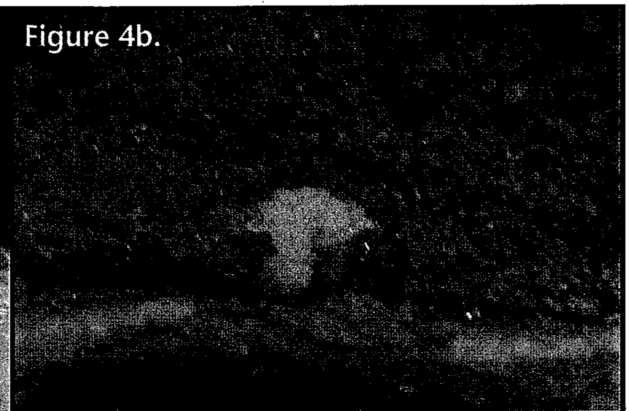


Figure 4b.


Figure 5a.

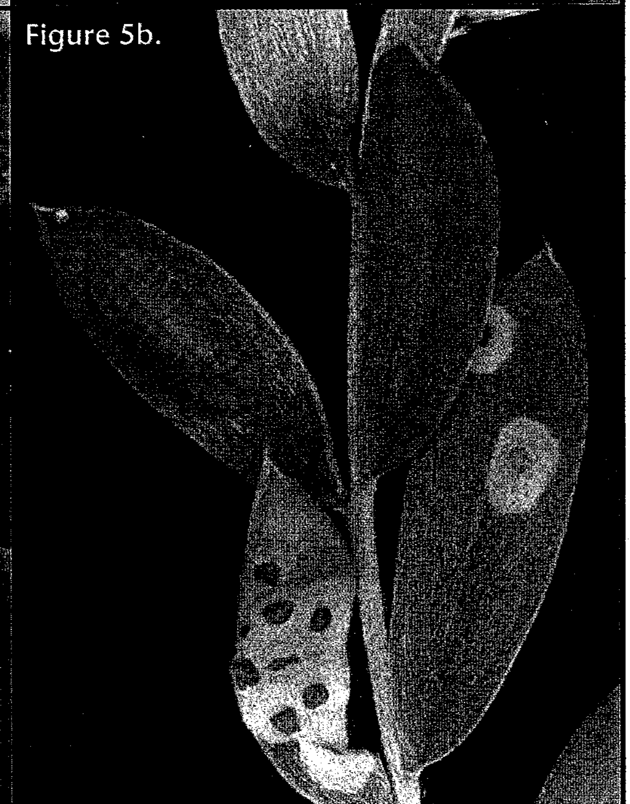


Figure 5b.


Figure 6.

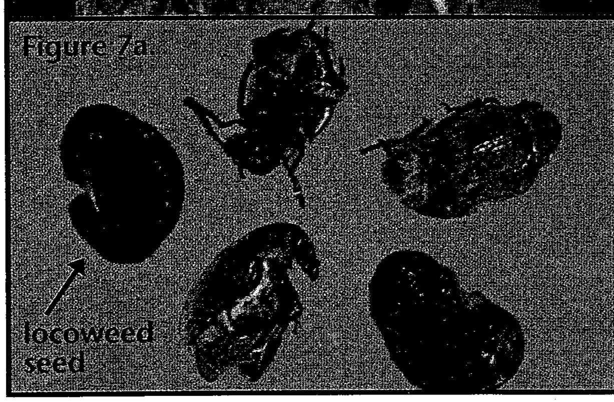


Figure 7a.

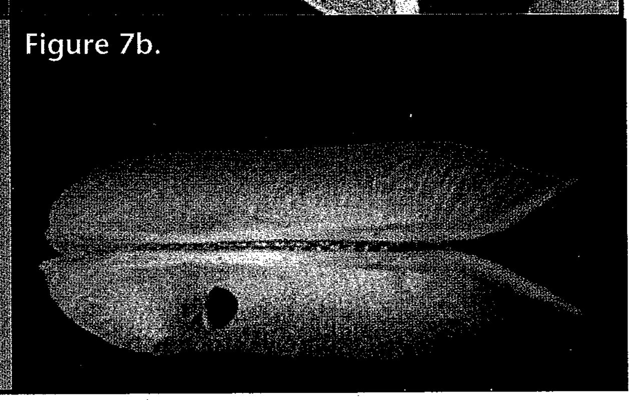


Figure 7b.

Understanding the Locoweed Weevil's Life History and Damage Potential

Mark Pomerinke, David C. Thompson, and Kevin T. Gardner

Locoweed weevil feasts only on woolly locoweed, making it a promising biological control agent.

The usefulness of an insect as a biological control agent depends greatly on its life history, in other words, how it lives. After a potential biocontrol agent is found, it is necessary to determine the agent's host range, the way it develops, where it lives, and how and when it damages its target. The four-lined locoweed weevil has killed large stands of woolly locoweed in Texas and New Mexico.

To identify the range of plants that the four-lined locoweed weevil eats, we did a gut content analysis. This process involves dissecting the weevil's digestive tract to determine what it has been eating. We did gut content analyses on 80 adult locoweed weevils collected from fields in Union County, N.M. that were heavily infested with both woolly locoweed and weevils. The plant fragments and individual cells from the gut contents were compared to reference slides made from known plant materials from the field sites.

Thirty weevils had no plant material in their digestive tracts. The other 50 weevils had only locoweed in their digestive tract. No other type of plant material was observed in their guts—not even sweet clover, a related beneficial forage. Therefore, it is reasonable to conclude that this weevil only feeds on locoweed and will not feed on desirable plants, even though it commonly encounters many other plant species.

To study the life history of the four-lined locoweed weevil, we established plots near Amistad and Gladstone, N.M. We sampled these plots every two to three weeks from early spring to late fall. We carefully examined the roots of woolly locoweed and the soil around them for evidence of weevil larvae. We examined leaves for eggs and adults. The entire life cycle of the locoweed weevil is completed in one year. Females begin laying eggs in late summer and may survive the winter to begin laying eggs again in early spring. Most of the eggs tend to hatch in the spring. Females lay eggs where the stems of the locoweed plant grow out of the crown and tend to lay more eggs on larger plants than on small ones. Once hatched, the larvae feed along the tap root making their way down from the crown to the lower portion of the root.

We found live larvae on all sizes of plants, including seedlings that had germinated the previous fall or spring. However, weevils only completed development on plants with root crowns larger than 0.4 cm. Weevil larvae construct a chamber inside the root or in the soil adjacent to the root in which they pupate (a resting stage before becoming an adult). Adults emerge from the soil by digging their way to the soil surface, usually after mid- to late-summer rains.

Adult weevils feed on leaflets and to a lesser extent on locoweed stems. Although feeding by adults may stress locoweed plants and subsequently increase mortality from stress-related causes, the larvae are the most damaging stage and are responsible for the majority of locoweed mortality because they cut off the plant's ability to obtain water and nutrients.

As few as two locoweed larvae per plant can substantially reduce the number of locoweed plants in an area. We have found as many as 25 larvae per plant at our Amistad research site (fig. 1). In April 1992, locoweed weevil populations averaged 2 plants per square meter at this site. However, densities as high as 30 plants per square meter were recorded. By the end of September, locoweed density was less than 0.4 locoweed plants per square meter and by the next spring almost all locoweed plants were gone (fig. 1). Despite the low plant densities, a small population of locoweed weevils continue to attack the remaining plants. This insect is very important in controlling populations of woolly locoweed, although weevil populations tend to build up slower than the locoweed population. We currently are working on techniques to manage weevil populations that include collecting and redistributing eggs and adults from heavy populations to locations that do not have many weevils. This technique should encourage weevil populations to develop quicker than they do naturally resulting in more rapid and significant reductions in locoweed populations.

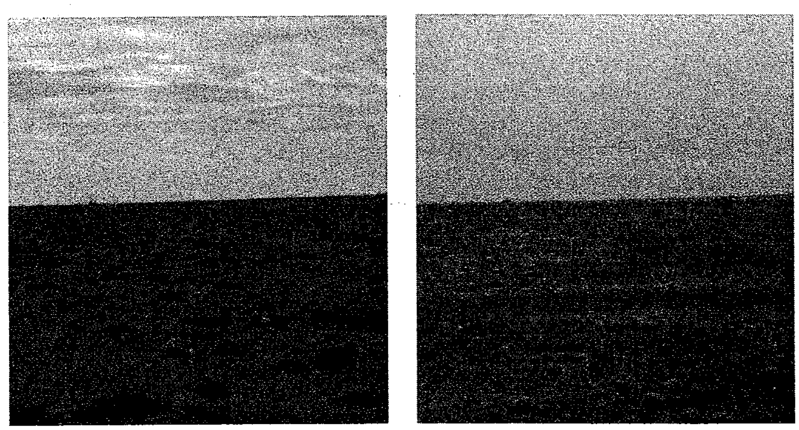


Figure 1. Mortality of woolly locoweed associated with four-lined locoweed weevil feeding at a site near Amistad, N.M. Pictures were taken from the same location on April 15, 1992 (left) and on April 19, 1993 (right).

Mark Pomerinke is a former graduate student, David C. Thompson is an associate professor of Entomology, and Kevin T. Gardner is a research assistant, all in the Department of Entomology, Plant Pathology, and Weed Science.

Locoweed Weevils Prefer Certain Varieties of Locoweed

David C. Thompson, Justin L. Knight, Tracy M. Sterling, and Kevin T. Gardner

Locoweed weevils like to eat the earlei *and* bigelovii *varieties of woolly locoweed.*

Six varieties of woolly locoweed have been identified in New Mexico: *mollissimus, earlei, mathewsii, mogollonicus, bigelovii,* and *thompsonae*. White locoweed also is common in northeastern New Mexico. The four-lined locoweed weevil has been found to feed and severely damage woolly locoweed varieties *mollissimus, earlei, matthewsii,* and *thompsonae*. The interactions between locoweed weevil and different varieties of locoweed are unknown. We wanted to see if weevils prefer one variety of locoweed over others, making them capable of more damage on sites where preferred varieties were common.

To find out, we collected seeds from mature plants of the six varieties of woolly locoweed and white locoweed and grew them in a greenhouse. Leaves from the plants were used to conduct choice and no-choice preference tests with adult weevils that were collected as larvae from the various sites where the seeds were collected.

We designed a choice test to determine the amount of leaf material adult weevils would eat given a choice of leaves from the six woolly locoweed varieties and white locoweed. Adult weevils preferred some varieties of locoweed over others (table 1). The weevils ate 140% more of the variety *earlei* than variety *mollissimus*. In conjunction with the choice test, we determined that weevils collected on a certain variety of locoweed did not necessarily prefer that variety when given a choice (fig. 1). The beetles preferred variety *earlei* no matter where the weevils were collected. When weevils were forced to eat one particular variety (no-choice test), the results were similar to those in the choice test (table 2). The locoweed weevil preferred to eat varieties *earlei* and *bigelovii* and fed the least on variety *mollissimus* in all experiments. White locoweed was largely ignored even in the no-choice test. We have never observed locoweed weevils feeding on white locoweed in the field, and apparently they do not use this closely related species as a food plant.

We do not know why variety *mollissimus* was least preferred by the weevils. Weevils are commonly collected from this variety of woolly locoweed and will regularly destroy large natural infestations of this locoweed variety. Woolly locoweed variety *mollissimus* is the most common woolly locoweed variety in New Mexico and it is possible that the large infestations of this variety are a result of the plants being partially resistant to weevil feeding. Although large weevil populations can be found in dense stands of variety *mollissimus*, weevils may not be as vigorous and healthy when feeding on this variety, which in turn may slow the growth rate of weevil populations, allowing increases in locoweed density.

Table 1. Average amount of locoweed consumed in 24 hours by the four-lined locoweed weevil given a choice of all varieties.

Locoweed	Variety	Amount consumed
		(mm^2)
Woolly locoweed	*earlei*	20.7
	mogollonicus	17.1
	bigelovii	16.8
	matthewsii	15.5
	thompsonae	12.5
	mollissimus	8.6
White locoweed	n/a	3.9

Table 2. Average amount of locoweed consumed in 24 hours by the four-lined locoweed weevil when forced to eat one variety.

Locoweed	Variety	Amount consumed
		(mm^2)
Woolly locoweed	*earlei*	64.8
	bigelovii	55.7
	matthewsii	50.6
	thompsonae	50.4
	mogollonicus	46.1
	mollissimus	38.6
White locoweed	n/a	12.0

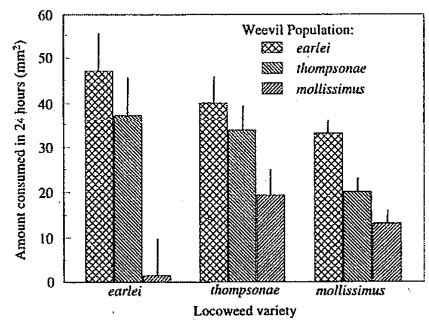


Figure 1. Choice test comparing the amount of woolly locoweed varieties consumed in 24 hours by adult four-lined locoweed weevils collected from each variety.

David C. Thompson is an associate professor of entomology, Justin L. Knight is a former graduate student, Tracy M. Sterling is an associate professor of weed science, and Kevin T. Gardner is a research assistant, all in the Department of Entomology, Plant Pathology, and Weed Science.

Are Rangeland Insect Spray Programs Enhancing Weed Problems?

Kevin T. Gardner and David C. Thompson

Insects feeding on the roots of locoweed are protected from the common insecticides used to control range caterpillars and grasshoppers.

Numerous ranchers have questioned whether using insecticides to control range caterpillars and rangeland grasshoppers also has increased locoweed and snakeweed populations by killing the nontarget beneficial insects that attack these weeds. Very little information is available about the influence of insecticides on biological control agents of weeds, especially insects that spend a portion of their life underground. We set up some experiments to determine if the most important biological control agent of woolly locoweed—the four-lined locoweed weevil—is killed by insecticides used to control rangeland pests.

Three commonly used insecticides for range caterpillar and range grasshopper (fig. 1) control were tested to determine the effect on the four-lined locoweed weevil, which commonly destroys large stands of woolly locoweed on rangeland. In early July, a common time for grasshopper and range caterpillar control in New Mexico, 35 plots (45-by-45 feet) were established in Lincoln County. The area was densely populated with woolly locoweed that had an average of 1.6 locoweed weevils feeding on each plant. The age of the weevil population was typical for this season–71% larvae, 15% pupae, and 14% adults that had not yet emerged from the ground. See *Common Locoweed-Feeding Insects* for pictures of the weevil at various life stages (p. 42).

Seven treatments including a non-sprayed control, were applied to the plots. Permethrin (trade name Pounce), the most widely used range caterpillar insecticide, was applied at four rates: 0.08 ounces per acre (most common rate used in northern New Mexico), 0.4 ounces per acre (five times the commonly used rate), 4 ounces per acre (manufacturer's recommended rate), and 40 ounces per acre (insecticidal check). Carbaryl (trade name Sevin) and acephate (trade name Orthene), both used for grasshopper control, were applied at the manufacturer's recommended rates of 1 quart per acre and 0.125 pounds per acre, respectively. One week after the chemicals were applied, 10 locoweed plants being attacked by locoweed weevils were dug from the ground in each plot. The weevils found were classified as either dead or alive.

There were no differences in the number of live or dead locoweed weevils found when any of the treatments were compared to the control plots (table 1). Soil type can influence the movement of insecticides into the plant's root zone. The soil at this site was a very heavy clay loam. In a similar experiment involving snakeweed growing in a very sandy soil, the two highest rates of permethrin resulted in 9% and 49% death of snakeweed borer larvae in the stems of treated snakeweed. Death of the beneficial insects living underground, even in sandy soils, did not occur until rates were used between 50 and 500 times higher than those applied in typical rangeland pest situations.

When they are still beneath the soil surface, locoweed weevils feeding on woolly locoweed growing in a heavy soil are not affected by the insecticides used in this experiment. These insecticides do kill insects feeding on the foliage, although the long-term impacts are still being studied. Since both range caterpillars and range grasshoppers are typically sprayed (fig. 2) between June and early August, most locoweed weevils are protected from the chemicals most commonly used in New Mexico. However, treating later than mid-August or prior to late May may result in the death of adult beetles after they have emerged from the soil.

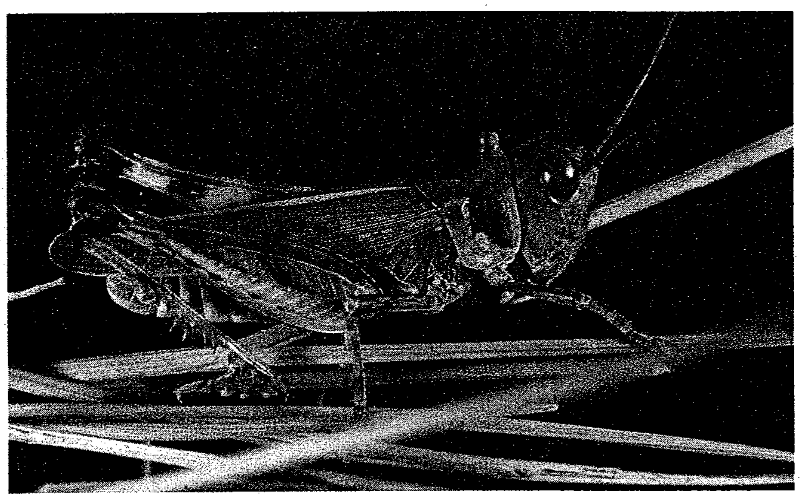


Figure 1. Range grasshopper.

Figure 2. Aerial application of insecticide.

Table 1. Number of live and dead four-lined locoweed weevil larvae*, pupae, and adults one week after applying common rangeland caterpillar and grasshopper control insecticides in Lincoln County, N.M.

	Larvae		Pupae		Adult		Combined total	
Treatment	Live	Dead	Live	Dead	Live	Dead	Live	Dead
Pounce (0.08 oz/ acre)	69	3	11	1	11	2	91	6
Pounce (0.4 oz/ acre)	64	4	8	2	6	2	78	8
Pounce (4.0 oz/ acre)	48	4	15	3	12	1	75	8
Pounce (40 oz/ acre)	69	4	9	4	7	0	85	8
Sevin (1 qt/ acre)	54	6	23	4	8	5	85	15
Orthene (0.125 lb/acre)	69	6	9	0	14	3	92	9
Control	58	3	5	5	13	4	76	12

* Number of live or dead locoweed weevils in treated plots are not different from those in the control plots.

Kevin T. Gardner is a research assistant and David C. Thompson is an associate professor, both in the Department of Entomology, Plant Pathology, and Weed Science.

Controlling Locoweed with Herbicides

Kirk McDaniel

White locoweed and woolly locoweed can be controlled at all growth stages by several different herbicides. It pays to spray under ideal weather conditions and shop for the best herbicide price.

Most herbicides used on rangelands are designed to remove targeted weeds but not harm other beneficial plants. The characteristics of each chemical is unique and the purpose for field testing these products side-by-side is to determine their relative strengths and weaknesses for controlling weeds. Between 1992 and 1997, I examined 28 different herbicide combinations during 18 field trials at four locations in northeastern New Mexico. The target weeds were white and woolly locoweed.

The herbicides were broadcast with a hand-held CO_2 pressurized sprayer to small, 30-by-30 foot plots that were replicated two or three times at each location. A portable weather station was set up during all spray operations to obtain air temperature, soil temperature at 6 inches, relative humidity, and wind speed and direction. About 12 months after spraying, white and woolly locoweed control was visually estimated by comparing treated to adjacent nontreated plots. When broom snakeweed was present, I estimated its control in the same way. Fringed sagewort and Bigelow sagebrush are not toxic and offer some forage value; however, these low-growing shrubs increase with disturbance and can suppress the growth of more desirable forage so control of these species was also estimated.

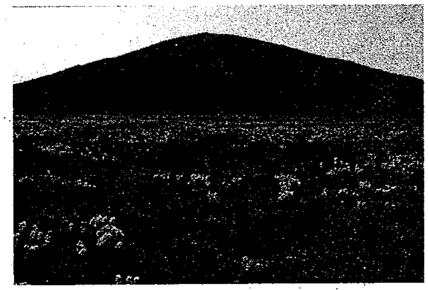
White locoweed experiments were timed to coincide with three white locoweed growth stages: early vegetative (April to mid-May), bloom or flowering (late May and June), and late vegetative (September to mid-October) (table 1). The woolly locoweed experiments were conducted in the spring and fall (table 2). Averaged across years and spray locations, herbicide treatments were rated as excellent (>95% control), good (85 to 94% control), fair (70 to 84% control), and poor (<70% control). These categories are arbitrary but I believe they fall within a range of satisfaction that the landowner might anticipate after applying these herbicides. Product performance cannot be guaranteed and failures do occur about 3 to 10% of the time.

Picloram (0.375 lb/acre) applied alone or mixed with 2,4-D (1:4 ratio at 1.25 lb/acre), provided excellent control of white locoweed and woolly locoweed (table 1 and 2). Metsulfuron (0.375 oz/acre) and clopyralid (0.25 lb/acre) also gave excellent control when sprayed during flowering and after flowering. The price of these products at the proper rate of application will influence herbicide choice. It definitely pays to shop around with dealers and applicators before purchasing a product. If spraying is only done under ideal environmental conditions the lower and more economical rates of picloram (0.25 versus 0.375 lb/acre), clopyralid (0.125 versus 0.25 lb/acre), and metsulfuron (0.18 versus 0.375 oz/acre) can give control results comparable to the higher rates.

Weather conditions when spraying often dictate the effectiveness of an herbicide. I found from the experiments conducted in northeastern New Mexico that irrespective of what herbicide is used that white locoweed control will be poorer when:

- Soil temperatures at 6 inches are below 55°F. Cold soils occur when locoweed is in the vegetative stage and spraying is done too early in the season.

- Locoweed vigor is low because soils are dry or plants are crippled by insects, thereby reducing herbicide movement through the plant.
- Rain occurs within four hours of spraying, resulting in the chemicals being washed off the leaves.



I also found that best control was under the following conditions:

- Relative humidity was high (above 50%); wind speed was low (<8 mph); and air temperatures were moderate (near 60 to 75°F is ideal). These conditions keep droplets wet longer, increasing herbicide absorption into the leaves.
- Soil temperatures were above 55°F at 6 inches, and soils were moderately moist, allowing plants to grow vigorously.

Table 1. Comparison of herbicides for white locoweed control.

Herbicide	Dosage	Locoweed growth stage: Early vegetative[1]	Bloom[2]	After flower–late vegetative[3]
	(lb ac/ac)			
Picloram	0.25	F[4]	G	G
Picloram	0.375	E	E	E
Picloram + 2,4-D (1:4)	0.47	E	E	G
Picloram + 2,4-D	0.625	E	E	E
Picloram + clopyralid (1:1)	0.25	E	E	E
Picloram + clopyralid	0.50	E	E	E
Picloram + dicamba (1:1)	0.25	F	G	G
Clopyralid	0.125	F	G	G
Clopyralid	0.25	G	E	E
Clopyralid + 2,4-D	0.125 + 1.0	G	F	P
Clopyralid + dicamba	0.125 + 0.25	G	G	E
Clopyralid + triclopyr (1:2)	0.25	P	G	G
Dicamba	0.50	P	G	G
Dicamba + 2,4-D (1:3)	1.0	P	G	F
Dicamba + 2,4-D	2.0	G	G	G
Triclopyr	0.25	P	F	F
Triclopyr + 2,4-D	0.125 + 1.0	F	F	F
Metsulfuron	0.1875 oz/ac	F	E	G
Metsulfuron	0.375	F	E	E
Metsulfuron + 2,4-D	0.1875 + 1.0	G	E	G
2,4-D	1.0	P	P	P
2,4-D	2.0	P	G	P
2,4-D	4.0	F	G	P

[1]Spraying for early vegetative was between April 1 and May 15.
[2]Spraying for bloom was between June 1 and June 15.
[3]Spraying for late vegetative was between September 1 and October 15.
[4]E = Excellent control; G = Good control; F = Fair control; P = Poor control.

- Spraying was completed in the morning rather than in the afternoon, because the ideal weather conditions required for optimum control are more likely to occur during this part of the day.

For those interested in "killing two birds with one stone," I've provided the relative effectiveness of the herbicides for control of broom snakeweed, fringed sagewort, and Bigelow sagebrush (table 3). Keep in mind that when locoweed is sprayed as the target plant, this may not be the ideal time for control of the other plants. For example, the best time of year to spray broom snakeweed is during its post-flower stage in October and November. The best way I found to target locoweed and to also control these alternative plants is to apply picloram + 2,4-D (1:4 ratio at 1.25 lb/acre) in spring or fall.

Table 2. Comparison of herbicides for woolly locoweed control near Gladstone, N.M.

Herbicide	Dosage	Woolly locoweed	
		Spring	Fall
	(oz/ac)		
Metsulfuron	0.188	F[1]	E
Metsulfuron	0.375	E	E
	(lb/ac)		
Picloram + 2,4-D (1:4)	0.94	E	E
Picloram	0.25	E	E
Picloram	0.375	E	E
Picloram + dicamba (1:1)	0.25	F	G
Dicamba	0.5	F	G
Dicamba + 2,4-D (1:4)	1.25	P	G
2,4-D	4.0	F	F
Triclopyr + 2,4-D (1:2)	0.75	P	G
Clopyralid	0.25	E	E

[1]E=excellent control, G=good control, F=fair control, P=poor control.

Table 3. Comparison of herbicides for broom snakeweed, fringed sagewort, and Bigelow sagebrush control.

Herbicide	Dosage	Snakeweed			Sagewort			Sagebrush		
		A[1]	J	S	A	J	S	A	J	S
	(lb/ac)	(% control)								
Picloram	0.25	95	73	89	13	0	75	12	0	75
Picloram	0.375	99	93	99	94	22	73	84	10	23
Picloram + 2,4-D (1:4)	0.94	94	95	92	16	27	77	16	10	63
Picloram + 2,4-D	1.25	99	100	96	38	30	87	27	3	63
Picloram + dicamba (1:1)	0.25	64	57	63	8	7	77	8	3	63
	(oz/ac)									
Metsulfuron	0.188	65	58	61	17	58	50	9	20	18
Metsulfuron	0.375	69	89	29	67	75	85	47	60	2
Metsulfuron + 2,4-D	0.188+1.0	98	15	58	19	40	7	7	7	37
	(oz/ac)									
Dicamba	0.5	49	59	66	8	7	35	8	3	17
Dicamba + 2,4-D (1:4)	1.25	51	90	37	22	12	53	23	15	15

[1]A = April, J = June, S = September.

Kirk McDaniel is a professor of range science in the Department of Animal and Range Sciences.

Do Differences in Locoweed Leaf Surfaces Affect Herbicide Uptake?

Tracy M. Sterling and Heidi S. Jochem

Additives increase herbicide uptake by locoweed regardless of leaf hair architecture.

Once a herbicide droplet lands on a leaf surface, the fate of the herbicide in the plant depends entirely on its uptake into the leaf. In most cases, the majority of applied herbicide remains on the leaf surface and never is absorbed into the plant. The major barrier to uptake of foliar-applied herbicides is the cuticular surface covering all parts of the plant. This surface is generally waxy and can contain leaf hairs known as trichomes. To improve uptake of the herbicide, it is necessary to understand the plant's characteristics, the herbicide and its carrier solution and the environmental conditions during herbicide application. By increasing uptake, weeds may be managed more efficiently, because there will be more herbicide in the plant. Therefore, we studied the leaf surface character of two locoweed species, white locoweed and woolly locoweed. We also evaluated the uptake of picloram and metsulfuron, two major herbicides used to control these weeds.

The surfaces of white locoweed and woolly locoweed both contain numerous hairs or trichomes; however, the hair structures of these two locoweeds are quite different. Leaves of white locoweed are covered with fine hairs that lie close to the leaf surface (fig. 1), giving a whitish-gray appearance. Hairs on woolly locoweed leaves are more upright and perpendicular to the leaf surface (fig. 2), giving a woolly appearance.

We measured herbicide uptake into locoweed leaves by applying individual drops of picloram or metsulfuron solution, two common herbicides used for locoweed control, at the recommended rates of 0.5 lb ae/acre and 7 g ai/acre in an application volume of 20 gal/acre. We also compared herbicide uptake using solutions containing diesel oil (14.3% by volume). After 24 hours, the herbicide remaining on the plant surface was rinsed off and then the amount of herbicide in the plant was measured.

Average uptake of the herbicides applied in water ranged from 8 to 12% for picloram and from 14 to 15% for metsulfuron (table 1). There was no statistical difference in uptake of either herbicide between these two locoweed species. However, when we added diesel oil, uptake of both herbicides increased dramatically in both species (table 2). Picloram uptake increased about sevenfold in both locoweed species when diesel oil was included. Metsulfuron uptake increased threefold in woolly locoweed and eightfold in white locoweed, when diesel oil was included. Thus, additives increase herbicide uptake by locoweed leaves, but the amount of the increase in uptake depends on the plant species and the herbicide.

Our results suggest that locoweed leaves absorb similar amounts of picloram and metsulfuron, regardless of their leaf surface characteristics when applied in water. However, additives, such as diesel oil, influence the uptake of these species differently. Further study is needed to better understand these interactions and how they might improve locoweed management.

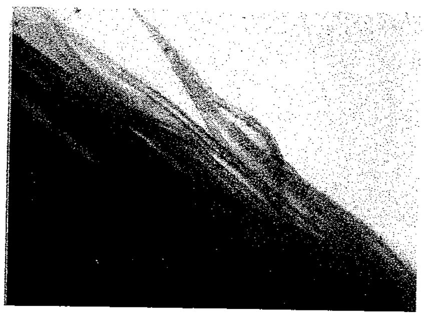


Figure 1. Leaf surface of white locoweed (10X magnification).

Figure 2. Leaf surface of woolly locoweed (10X magnification).

Table 1. Herbicide uptake by locoweed leaves after 24 hours.

Locoweed species	Picloram uptake	Metsulfuron uptake
	(% of applied)	
Woolly locoweed	8.9	15.3
White locoweed	11.8	14.5

Table 2. Herbicide uptake by locoweed leaves after 24 hours, when diesel oil (14.3% by volume) was included.

Locoweed species	Picloram uptake	Metsulfuron uptake
	(% of applied)	
Woolly locoweed	83.4	47.3
White locoweed	81.4	79.9

Tracy M. Sterling is an associate professor of Weed Science and Heidi S. Jochem is a former research assistant, both in the Department of Entomology, Plant Pathology, and Weed Science.

Understanding Why White Locoweed is More Sensitive to Herbicides than Woolly Locoweed

Tracy M. Sterling and Heidi S. Jochem

Differences in uptake, translocation, and metabolism don't explain why locoweed species react differently to herbicides, but differences in its site of action might.

Managing locoweed on New Mexico rangelands sometimes includes the use of chemical controls. Two major herbicides used for managing locoweed include picloram and metsulfuron. To improve herbicide use efficiency and reduce application costs, it is important to understand interactions among locoweed physiology, herbicide action and the environment. However, information concerning the behavior and fate of herbicides in locoweeds has not been reported. A better understanding of how herbicides act in the plants should help increase locoweed control on rangelands.

We conducted studies to evaluate the relative toxicity of metsulfuron and picloram applied to white locoweed and woolly locoweed leaves. We wanted to find out if there are any differences in uptake, translocation, and metabolism of metsulfuron and picloram when applied to the foliage of the two locoweed species. Differences in these processes can greatly influence herbicide effectiveness. Reduced uptake lowers the amount of herbicide entering the plant and, thus, lowers herbicide activity. Reduced translocation decreases the distribution of the herbicide throughout the plants and lowers herbicide activity. Reduced herbicide metabolism increases the amount of herbicide available in its toxic form, enhancing herbicide activity.

We compared the sensitivity of greenhouse-grown woolly locoweed and white locoweed to increasing rates of foliar-applied picloram and metsulfuron. Woolly locoweed was more tolerant than white locoweed to both herbicides (fig. 1). The herbicides are recommended for controlling both species. However, differential sensitivity between the locoweeds to the herbicides has not been compared directly in the field, possibly because white locoweed and woolly locoweed generally grow in different communities, although mixed populations do exist. Because of this differential sensitivity, we conducted further studies to determine why white locoweed was more sensitive than woolly locoweed to both herbicides.

We compared the uptake, translocation, and metabolism of these herbicides by both locoweed species. Interestingly, in *Do Differences in Locoweed Leaf Surfaces Affect Herbicide Uptake?* (p. 55), there was no difference between these two locoweed species in uptake of either herbicide even though their leaf surfaces are quite different. To study differences in translocation and metabolism, we applied each herbicide as individual drops at their recommended rates in an application volume of 20 gal/acre. A surfactant and diesel oil were included to increase uptake into the plant. After 96 hours in the greenhouse, the herbicide remaining on the plant surface was rinsed off. Plants were then dissected and herbicide content determined in the treated leaves and leaves located above and below the treated leaves. In addition to determining the quantity of each herbicide in the plant parts, we determined whether or not the her-

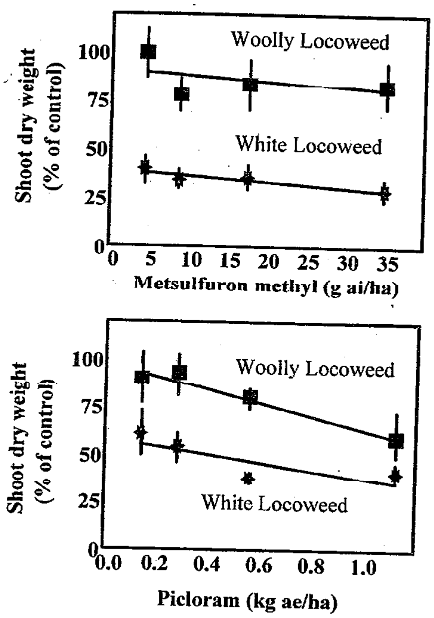


Figure 1. Rate response of woolly locoweed and white locoweed 42 days after applying picloram or metsulfuron with surfactant.

bicide was still in its original form or if it had been chemically altered by the plant to a less toxic compound.

There was no difference in metsulfuron (table 1) or picloram (table 2) movement out of treated woolly locoweed or white locoweed leaves. In fact, more than 94% of both herbicides remained in the treated leaf tissue of both locoweed species 96 hours after treatment, suggesting that differences in herbicide translocation do not explain differences in tolerance to either herbicide.

In terms of metabolism, neither species altered metsulfuron, and no metabolites of this herbicide were found in either locoweed species. Therefore, metsulfuron is available to both species in its toxic form. In contrast, both locoweed species altered picloram to an unknown metabolite. Picloram was metabolized to a similar extent in both species with almost 70% remaining as picloram (table 3). Thus, differences in metabolism do not explain differences in tolerance of these two species to picloram and metsulfuron.

Because neither uptake, translocation, nor metabolism could explain the greater sensitivity of white locoweed over woolly locoweed, we investigated differences at the site of metsulfuron action specifically. Because the site of picloram action is unknown, we couldn't investigate that question. Metsulfuron kills sensitive plants by blocking acetolactate synthase (ALS), a key enzyme needed to produce important amino acids in plants. This site of action classifies metsulfuron as an ALS inhibitor. If the ALS enzyme is more active, or in other words if it is present at higher levels or works faster in woolly locoweed than in white locoweed, woolly locoweed would be able to deal with more herbicide before showing injury from the herbicide. When we measured how much enzyme activity was present in both locoweed species, we found woolly locoweed exhibited almost twice as much activity as white locoweed. Thus, woolly locoweed is more tolerant to metsulfuron than white locoweed, because it either contains more of the key, target enzyme or it contains a more active form of the enzyme. This means that even when metsulfuron enters woolly locoweed, there is more enzyme present to be inhibited, leading to woolly locoweed's reduced sensitivity to metsulfuron as compared to white locoweed.

Table 1. Metsulfuron translocation by woolly locoweed and white locoweed after 96 hours.

Locoweed species	Metsulfuron content in plant sections: Treated leaf	Above treated leaf	Below treated leaf
	(% of absorbed metsulfuron)		
Woolly locoweed	98.4	0.7	0.9
White locoweed	99.0	0.5	0.5

Table 2. Picloram translocation by woolly locoweed and white locoweed after 96 hours.

Locoweed species	Picloram content in plant sections: Treated leaf	Above treated leaf	Below treated leaf
	(% of absorbed metsulfuron)		
Woolly locoweed	99.1	0.7	0.2
White locoweed	93.7	2.8	0.5

Table 3. Picloram metabolism by woolly locoweed and white locoweed after 96 hours.

Locoweed species	Picloram remaining	Metabolite present
	(% of absorbed picloram)	
Woolly locoweed	68.2	31.8
White locoweed	67.2	32.8

Tracy M. Sterling is an associate professor of weed science and Heidi S. Jochem is a former research assistant, both in the Department of Entomology, Plant Pathology, and Weed Science.

Improving Herbicide Application for Locoweed

Ellis Huddleston, Mark Ledson, Jim Ross, and Ken Giles

We evaluated a new pulse-modulated spraying system for ground and aerial herbicide application to control locoweed. This system allows control of droplet size and spray volume.

The size of herbicide spray droplets is important to control weeds successfully and economically. Cost is critical in controlling rangeland weeds, especially locoweed and broom snakeweed, because of the low per-acre value of rangeland. Small droplets tend to drift long distances and may evaporate so fast that most of the herbicide does not get into the plant. Droplets that are too large may not provide adequate coverage of the plant. But they do dry slower than smaller droplets, so more herbicide gets into the plant.

Changing temperature, relative humidity, and wind speed during a spraying operation may require changes in droplet size for most effective control. This pulse-modulated system (fig. 1) makes immediate changes possible from the driver's or pilot's seat. A high-speed solenoid cycles the nozzle on or off in one-tenth of a second intervals. For example, the nozzle can be off five cycles and on one cycle to give an 80% reduction in spray volume to reduce the amount of water needed for spraying.

We conducted these studies in NMSU's wind tunnel test facility. Wind speeds were changed to simulate ground and aerial application. We measured droplet sizes with an instrument called a laser particle size analyzer.

The 8004 fan nozzle is often used for ground application of herbicides (fig. 2). With this nozzle, droplet size can be varied from small to large, while changing the spray volume from 20 to 2 gallons per acre. We were able to reduce the "fines" (extremely driftable droplets) from 9% to 0.5% of the total spray volume. For aerial application, the range in droplet sizes was less. Also, the amount of "fines" increased, due to the wind shear across the nozzle at aircraft speeds.

The CP™ nozzle is the most widely used nozzle for aerial application of herbicides. This nozzle has coarse, medium, and fine settings to vary the droplet size. The pulse-modulated system can be used with the CP™ nozzle to vary the spray volume while flying. We also learned that the nozzle setting can have a significant effect on the amount of very small drops that lead to increased spray drift.

Solid stream (SS) nozzles (disc without a core) are required in some states for certain aerial herbicide applications. We found that spraying pressure had very little effect on the size of the droplets in aerial spraying. In ground applications, pressure is the most important factor in droplet size.

We tested a nozzle called the Lund nozzle. This nozzle is a specialty nozzle used for aerial application of herbicides in the northwestern United States. At helicopter speeds, it makes very large droplets. When speed was increased to airplane speeds, the droplets became much smaller. These changes show that air speed has a major effect on droplet size.

With traditional spraying systems, only nozzle size, nozzle type, pressure and speed can be varied. Speed is difficult to change on rangeland, because the terrain limits how fast ground equipment can go. Aircraft operate in a relatively narrow speed range. Changing nozzle type is one option, but uniform coverage may be difficult to achieve with some types, especially for ground spraying. Changing pressure will change droplet size but also will change spray volume. Selecting a larger nozzle increases droplet size and spray volume. None of the above options offer a wide range of droplet sizes and spray volumes.

We found that the pulse-modulation system allows the operator to vary the flow rate from 100 to 10% of full flow without changing the droplet size markedly. A very large nozzle, capable of making large droplets, can be operated at a reduced flow rate to give the same volume as a smaller nozzle. This system overcomes the problem of having to use 20 gallons of spray per acre to have ground equipment operate correctly. With pulse-modulation, the same rates (2 to 5 gal/acre) as aerial application are possible.

Changing pressure and flow rate gives a wide range of droplet sizes, especially for ground application. A wider range of droplet sizes can be achieved with ground spraying than with aerial application because of the influence of wind shear. This problem can be offset, because aerial application can use a wider range of nozzle types effectively.

We found that by using the pulse-modulation technique and carefully choosing nozzle type, herbicide spray applications can be tailored to particular sites, weeds, and weather conditions.

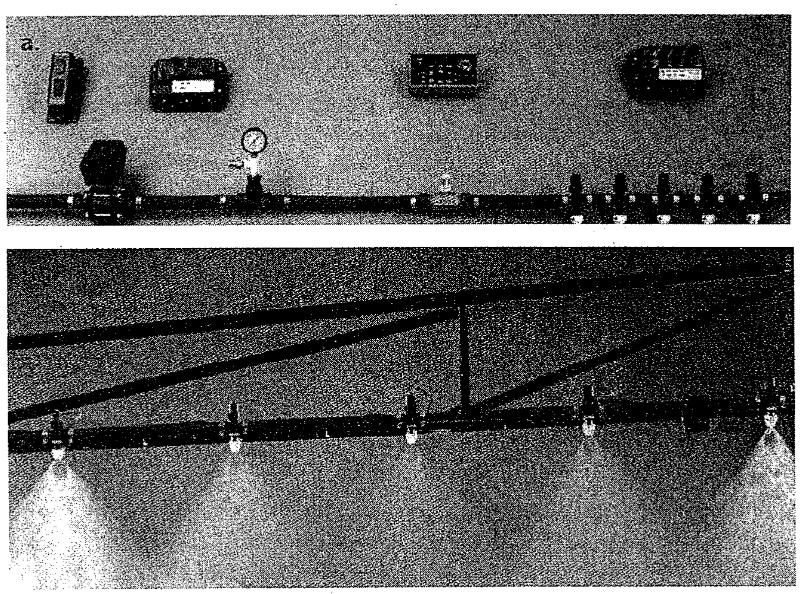


Figure 1. A complete pulse-modulated sprayer of spraying system showing the controllers and a test spray boom (a). Nozzles are usually 20 inches apart on a ground sprayer (b).

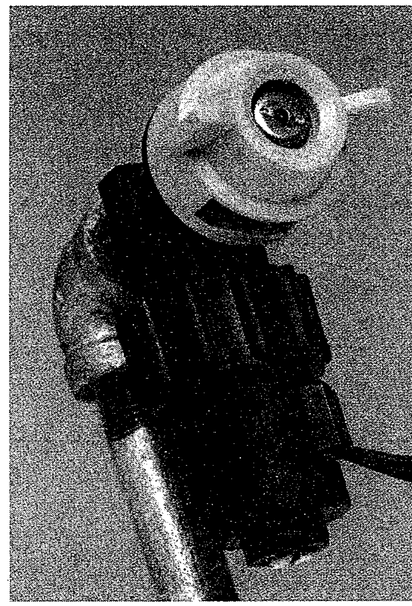


Figure 2. Regular sprayer nozzle retrofitted with pulse-modulation solenoid.

Ellis Huddleston is a professor of entomology and Mark Ledson and Jim Ross are research specialists, all in the Department of Entomology, Plant Pathology, and Weed Science. Ken Giles is a professor of agricultural engineering in the Department of Biological and Agricultural Engineering at the University of California, Davis.

How Long Does Locoweed Control Last?

Kirk McDaniel

Applied at the proper rate, picloram and other herbicides can eliminate locoweed. Pastures will remain locoweed-free until conditions are ideal for seeds to germinate, creating a new population.

To estimate (and to a certain extent, guess) how long herbicide control will last depends on two separate but equally important considerations: first, how effective was the initial treatment, and second, how often do the needed environmental conditions occur that trigger locoweed germination.

Let's consider the first point. Herbicide treatments, especially those that include picloram in the mixture, kill most if not all locoweed roots within two months of spraying. One year after treatment the area should be locoweed-free and remain this way indefinitely until new plants propagate from seed. If live locoweed are found the year after spraying, this likely means the herbicide only top-killed the plants but the root system survived. This results in locoweed plants that appear dead at first but later they produce new foliage. Check this out by digging up plants to verify if the growth is from older roots or if indeed plants are being produced from seed. I've noticed locoweed plants sprayed with some herbicides, such as 2, 4-D or dicamba, often appear dead the first season after spraying. But new shoots are produced the next year because the roots didn't die.

Now, consider the second point. How long locoweed seed remains viable in the topsoil is not precisely known, but conservative estimates exceed 10 years. The hard, impervious seed coat allows a large reserve of locoweed seed to remain buried in soil until optimum germination conditions occur. The longevity of seed and the large seed reserve in the soil support the cyclic nature of locoweed plant populations. Herbicides used to control locoweed do not harm seed already in the soil, nor do the chemicals prevent these seeds from germinating. It can be argued that eliminating locoweed through spraying reduces future seed contributed to the seed bank. However, because the seed lives so long, it may be unrealistic to imagine that the soil may someday be free of locoweed seed. The environmental requirements for locoweed germination are not completely understood but typically conditions suited for propagation of white or woolly locoweed occur about once or twice a decade. That is, while a few new plants may be added to a local population in a given year, major germination events occur infrequently.

In this study, I considered how the long-lived white locoweed seed that only germinates under specific environmental conditions affects the life of herbicide treatments (fig. 1). In a series of experiments, picloram was sprayed every spring from 1992 through 1997 at various locations in northeastern New Mexico. The picloram treatment always killed 100% of the locoweed in research plots and few new plants were observed in any of the sprayed areas until October 1997. During late summer 1997, rainfall was above normal throughout much of northeastern New Mexico and this apparently triggered white locoweed to germinate. I counted all the new white locoweed seedlings in research plots sprayed earlier in 1992 and 1993, and found they roughly had the same number of seedlings as nonsprayed areas. Plots sprayed in 1994, 1995, and 1996 had fewer seedlings in sprayed areas compared to nonsprayed areas, but the number of returning plants was judged to be too many. Thus, treatment life could be interpreted as lasting six years or less depending on the year sprayed. Interestingly, and I have no explanation for this, plots sprayed with picloram in spring 1997 had no seedlings when counts were made in the fall.

Another important consideration for determining treatment-life is knowing how long locoweed naturally lives. Plant longevity is species specific. For example, woolly locoweed rarely persists in a given area more than a few years because insects, particularly the four-lined locoweed weevil, shorten their lives. It is not unusual to spray woolly locoweed one year and to find the next that it has disappeared from both sprayed and nonsprayed areas. White locoweed, on the other hand, is longer lived (probably up to 10 years). Thus, when spraying woolly locoweed the objective should be to simply remove plants currently present. With white locoweed, longer-lasting control of a persistent population may be a more important consideration.

As part of my locoweed management research program, repeated spraying on previously controlled areas is being investigated to examine the possibility of depleting the soil seed bank of white locoweed. This is speculative of course, but for example, by early elimination of new plants propagated in summer 1997, it may be possible through time and repeated spraying to drain seed from the soil. I can only hypothesize at this point, but it is obvious that a single spray treatment will control a locoweed for a few years, it will not remove the population forever.

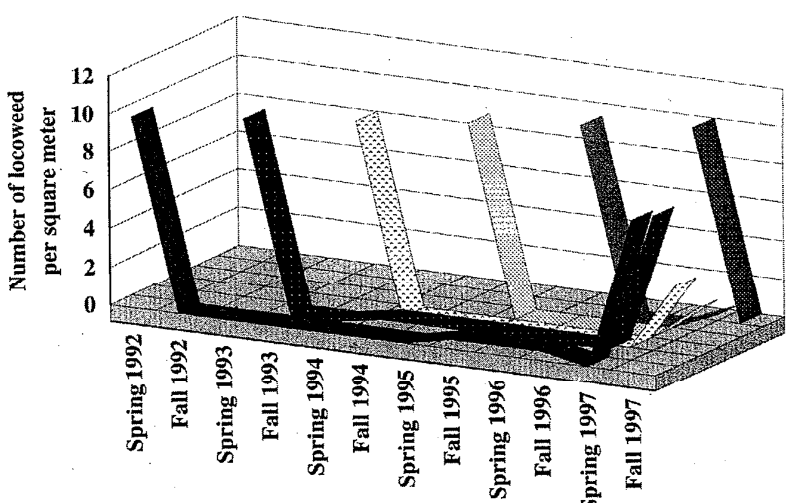


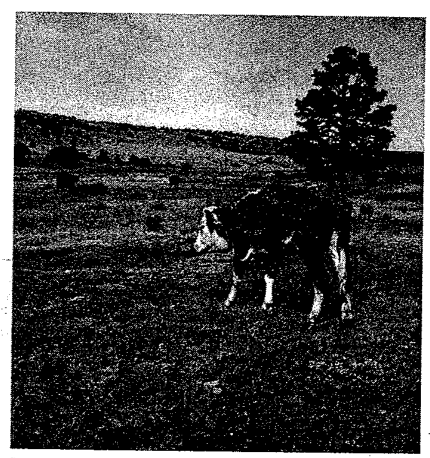
Figure 1. White locoweed control and reestablishment after spraying.

Kirk McDaniel is a professor of range science in the Department of Animal and Range Sciences.

Reducing Locoism with Management Decisions

Chris Allison and J. David Graham

Evaluating old and new locoweed management options to minimize damage to cattle



Woolly locoweed and white locoweed are common in northeastern New Mexico. Both species are highly toxic, but their growth habits and site preferences are very different. Woolly locoweed tends to cycle in and out depending on moisture conditions and insect populations. It also prefers deeper, more fertile soils and is found in high numbers in old fields or other disturbed sites.

White locoweed can be found at anytime of the year and during wet or dry years. It is a perennial plant and does not exhibit the cycles of abundance seen with woolly locoweed. White locoweed doesn't appear to be affected by insects. Shallow soils, especially those of volcanic origin, are home for white locoweed. Cattle generally prefer white locoweed over woolly locoweed.

Locoweed is poisonous to any animal (or human) that eats it. Poisoning is more prevalent when locoweed is green and the grass is brown. Cattle typically eat locoweed prior to warm-season grass growth and again when those grasses start maturing in the late summer or early fall. Therefore, we are dealing with a "safe" period of only 90 to 120 days.

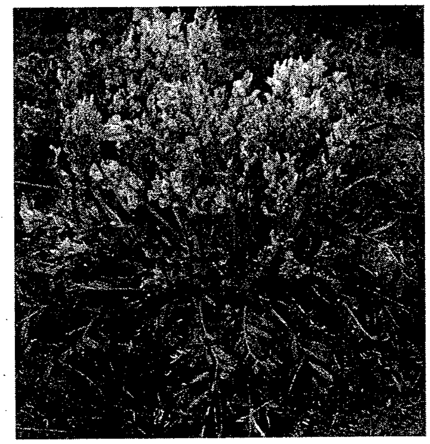
Management recommendations made in this paper are really best guesses as we have witnessed exceptions to all of these recommendations. Just when you think you have the locoweed problem figured out, you'll probably be proven wrong by the cattle and the plant. During the last six years, we have developed some management options based on research as well as observation. We will discuss management programs that work well to minimize locoism. We'll also address some of the old recommendations that we think are not valid. We will discuss these first.

1. *Graze cattle that are familiar with the range.* This is probably counterproductive, because cattle learn to eat plants, especially locoweed, from older, more experienced animals. This behavior often is called social facilitation, or "peer pressure." Naive cattle that have never grazed locoweed are a safer bet.

2. *Don't graze wheat pasture cattle on locoweed rangeland.* This old recommendation assumes that cattle coming off wheat are more likely to graze green plants such as locoweed. Research conducted during this project found no difference in locoism incidence between wheat pasture cattle and native range cattle. All cattle prefer green locoweed to brown grass. Wheat pasture cattle are no more likely to graze locoweed than other cattle.

3. *Supplement cattle with plenty of salt and minerals.* The idea that cattle are more likely to graze locoweed if deprived of salt and minerals is not conclusive. We highly recommend range livestock receive good mineral, protein, and energy supplements when vegetation warrants supplementation. However, the only way a supplement will reduce locoism is if it prevents cattle from grazing locoweed. Thus far, no such supplement exists.

What can you do? Next, we will discuss options that have been proven to reduce locoism.



1. *Create locoweed-free areas*. It would be nice to be able to spray the entire ranch. However, this is not economically feasible for everyone and may not be necessary. Creating pastures that are free of locoweed provides greater management flexibility when a "safe" area is needed.

2. *Observation*. Removing cattle that are observed eating locoweed provides relief to the animals and also prevents them from teaching other cattle to eat locoweed.

3. *Range readiness*. Don't graze locoweed-infested pastures until blue grama has started growing. This date varies from year to year, but by June 1, warm-season grasses should provide enough green feed to keep cattle from searching for locoweed. The other danger period is in the fall, when grasses start curing and locoweed once again becomes a preferred plant.

4. *Cyclic grazing*. Grazing locoweed-infested pastures for less than 4 weeks followed by grazing a locoweed-free pasture for 4 to 6 weeks may avoid the need to totally abandon locoweed pastures.

5. *Rotational grazing*. Graze the locoweed-infested pastures during the "safe" period (June to September) and the locoweed-free pastures prior to June and after September. Remember, these dates are only guidelines and you will need to spend some time observing cattle grazing locoweed-infested pastures to determine when they quit locoweed and when they start grazing it again.

6. *Flash grazing*. Naive cattle normally will not graze locoweed until grazing pressure forces them to eat the plant. A series of trials were conducted near Des Moines, N.M. In the first trial, naive yearling cattle did not graze locoweed until grass use was heavy. In the second trial, the same cattle started eating locoweed when grass use was light to moderate. By the third trial, the same yearlings ate locoweed first and preferred it to other plants. Therefore, we recommend that grass use never be heavy or severe in order to prevent cattle from learning to eat locoweed.

7. *Culling*. Locoweed affects reproductive performance. Cows that are open in the fall need to be culled, because they probably have eaten locoweed and need to be sold. Culling open cows makes economic sense and also has proven to reduce the number of locoweed eaters on the ranch.

8. *Aversion*. Although this option is still experimental, we believe it offers a lot of promise for reducing locoism. Cattle have been trained to avoid eating locoweed through a process of conditioned food aversion. Cattle are fed locoweed, then dosed with an emetic, lithium chloride (LiCl), to induce gastrointestinal distress. The cattle associate locoweed's taste with a belly ache and avoid grazing it. Aversion training works best on naive cattle not familiar with locoweed. Steers familiar with locoweed require several doses. Dosage rate is critical, with 200 mg LiC1 per kg body weight being the most effective. Averted cattle must then be kept away from nonaverted locoweed eaters to prevent peer pressure from negating the aversion. This suggests the idea of averting replacement heifers so that their offspring will never be taught to eat locoweed.

We will continue to test and fine-tune these management options so that ranchers won't have to abandon weedy rangelands and livestock losses can be minimized.

Chris Allison is an Extension range management specialist and J. David Graham is a Union County Extension agent in Clayton, N.M., both with NMSU's Cooperative Extension Service.

Managing Cattle to Prevent Locoweed Poisoning

Michael H. Ralphs, J. David Graham, Glen Duff, and Lynn F. James

Cattle graze locoweed in the spring when it is green and growing and warm-season grasses are dormant, and in the fall when grasses dry out and locoweed regrowth occurs. Ranchers should deny cattle access to locoweed during these critical periods.

Woolly locoweed populations are somewhat cyclic. They grow and flourish in wet years, but die out during drought and/or in combination with insect damage. White locoweed populations are more persistent, although their numbers may decline in severe drought.

The growth pattern of both locoweeds leads to poisoning problems. They either remain green over winter, or are the first plants to green up in the spring. Livestock generally prefer the green, growing locoweeds to dry, warm-season grasses.

In seven grazing studies we have conducted, cattle readily grazed on white and woolly locoweed in March, April, and May, but stopped grazing the plants in June when warm-season grasses started rapid growth and locoweed matured. Even animals that were severely poisoned left locoweed for green grass as the grass became available. We also expect that cattle will start grazing locoweed in the fall when it resumes growth and warm-season grasses mature and go dormant. Poisoning also can occur in cattle grazing old, dry locoweed stalks that remain from previous years.

Locoweed can severely affect weight gains of stocker cattle. We found that yearling stocker steers lost weight as they became poisoned, and gains did not resume for 50 days after they stopped eating locoweed in early June (fig. 1). Steers that were aversely conditioned to prevent them from eating locoweed continued to gain weight throughout the season.

The simplest management solution is to deny cattle access to locoweed during the critical spring and fall periods when it is the only green feed available. White locoweed's preferred habitat is shallow rocky soils. Fencing along soil boundaries or vegetation types can provide management control for seasonal grazing. Herbicide control of locoweed in strategic locations also can provide locoweed-free pastures for critical times.

Locoweed was once thought to be addictive, but recent research has shown that preference for locoweed is relative to availability and condition of other forage. However, some animals learn to accept locoweed. These animals will influence others to start eating it. Peer pressure is a very strong force influencing others to sample locoweed. Livestock should be watched closely and removed if they start eating locoweed to prevent progressive poisoning and to prevent peer influence to start others grazing it.

Grazing pressure also can force cattle to start grazing locoweed if they run short of desirable forage, particularly green forage. Ranchers should not overstock locoweed-infested ranges, but should ensure that adequate forage is always available.

Cattle have been trained to avoid eating locoweed through the process of conditioned food aversion. We fed locoweed to cattle, then gave them an emetic (lithium chloride) to induce stomach sickness. The animals associated the taste of locoweed with the induced illness and subsequently avoided grazing it. Aversion conditioning worked best on new cattle that

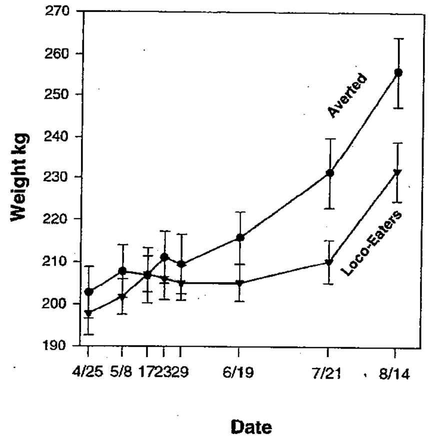
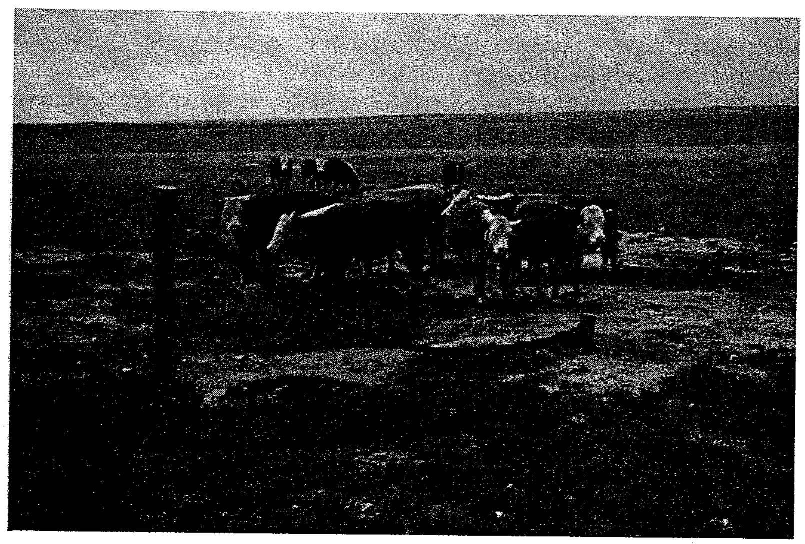


Figure 1. Weight gains of steers that ate locoweed and became poisoned (loco-eaters) compared to steers that were averted from eating locoweed (averted).

were not familiar with locoweed. Steers that were familiar with locoweed required several doses of lithium chloride following short periods of grazing locoweed in the pasture. Averted cattle must be kept separate from cattle that are grazing locoweed, because peer pressure will cause them to sample locoweed and they will continue to eat it.



Michael H. Ralphs is a rangeland scientist and Lynn F. James is the research leader, both at USDA's Agricultural Research Service, Poisonous Plant Research Laboratory in Logan, Utah. J. David Graham is a Union County Extension agent in Clayton, N.M. Glen Duff is director of NMSU's Clayton Livestock Research Center.

Developing Locoweed-Free Pastures

Kirk McDaniel and Chris Allison

Locoweed-free pastures add management flexibility to operations troubled by the poisonous plants.

Even though developing locoweed-free areas is not a new idea (many ranchers have used the strategy for years), it still makes sense as part of an overall effort to minimize locoweed's impact on an operation.

The idea is simple. First, identify pastures or portions of existing pastures that have little or no locoweed. If no such areas exist, create loco-free areas through fencing, spraying, or grazing management. The purpose is to have certain pastures available in the event animals become "locoed." In addition to acting as safe zones for recovering livestock, these areas can serve as reserves if forage becomes scarce elsewhere.

Is there a precedent for this concept?

Ranchers in southeastern New Mexico usually defer grazing pastures for 4 to 8 weeks in the spring to prevent ingestion of newly produced shinnery oak shoots and leaves that are high in tannin. Ranchers keep animals in "off-shinnery pastures" until leaves mature and become less palatable and enticing to the animals. In some cases, ranchers have had to control shinnery oak to create pastures free of the toxic plant.

How do I select areas to be identified as loco-free?

Every operation is unique. Terrain, water sources, and size and configuration of present pastures all influence how ranchers should proceed. The first step is to determine locoweed's distribution on the ranch—pasture by pasture. In some situations, it may occur only in areas of past disturbance, along side-slopes or at higher elevations. There may be some locoweed in every pasture, but the relative concentration will likely be less in certain areas. Pastures currently free of locoweed, or nearly so, should be the first ones chosen as safe havens from locoweed. After surveying the locoweed situation, ranchers should ask: Is it possible to fence portions of existing pastures with no locoweed? Can locoweed-free areas be created by fencing and spraying small locoweed populations or hot spots? Do areas with little locoweed lend themselves to flexible management?

How much area is needed?

Ideally, a minimum of one-quarter of a ranch's pastures or grazing areas should be locoweed-free to initiate some of the alternative management strategies described in this report. Every operation is unique so this is not a magic number. Obviously, as more locoweed-free areas become available, grazing management becomes easier.

How should a few plants or hot spots be eliminated in locoweed-free areas?

It's always possible that weather or insects will eliminate locoweed naturally. Woolly locoweed, for example, is short-lived and very susceptible to damage by root borers (see *Common Locoweed-Feeding Insects*, p. 42). Check the plants to see if larvae are feeding on the roots. If so, let the insects do their thing, as infested plants generally will die within a season or two. White locoweed is less susceptible to damage by insects

and often persists in a given area for years. Spraying with herbicide is usually the best alternative for eliminating these plants.

How should locoweed be sprayed?

Controlling all locoweed on a ranch is often unrealistic and unnecessary. Through careful planning and by targeting major trouble spots first, spraying time, effort, and expense can be reduced greatly. Irrespective of species, locoweeds are easily controlled by a broadcast spray of picloram + 2,4-D (Grazon P+D) at the equivalent of two quarts of herbicide product per acre.

Ranchers can contract with aerial applicators to provide the chemical and to spray large areas in need of control. Get best price estimates from two or three professional applicators who commonly do range brush and weed control work. Aerial spraying is common in New Mexico, and it is easy to obtain references for the best qualified applicators.

In some cases, producers may want to do the spraying themselves using a ground-sprayer, such as a trailer with a mounted boom. To do so, a pesticide applicator license is needed to purchase and apply the product. County Extension agents have more information about how to acquire a license. For a small amount of locoweed, a backpack sprayer can be used to spray plants individually with the herbicide mixed as a 5% solution in water.

Be sure to anticipate the need for follow-up control. Whether you grub plants or spray them, the plants are likely to return sometime with a "locoweed year." The problem usually is less severe, but repeat spraying is sometimes necessary.

Can cattle be used to make locoweed-free areas?

se this method but with caution. Flash grazing and other strategies are described in this report (see *Managing Cattle to Prevent Locoweed Poisoning*, p. 67). However, making sure animals don't eat the plant is the most sensible way to avoid locoism.

Should locoweed-free areas be changed or rotated from year to year?

An important grazing management goal should be to upgrade the land's quality and condition. Resting the same areas at the same time each year without equal rest for other areas will likely lead to some deterioration. It makes sense to incorporate loco-free areas into a dynamic and flexible grazing scheme.

How should cattle be managed with locoweed-free areas?

The most important point to emphasize is that the stocking rate needs to be adjusted according to the amount of land grazed. If grazing is deferred or reduced in certain pastures to prevent locoism, then cattle numbers need to be decreased proportionally to prevent overgrazing.

Kirk McDaniel is a professor of range science in the Department of Animal and Range Sciences and Chris Allison is an Extension range management specialist with NMSU's Cooperative Extension Service.

Degree of Locoweed Poisoning Predicts Yearling Stocker Performance

Les P. Owen, L. Allen Torell, J. David Graham, and Michael H. Ralphs

The more locoweed in the pasture, the less weight yearling stocker cattle gain.

In 1996, we conducted a grazing trial on the Mondragon Ranch near Des Moines, N.M. to evaluate production differences of yearling cattle with increasing levels of locoweed present on the grazing land. Yearling heifers (195 head) were grazed in pastures with three different degrees of locoweed infestation: no locoweed, moderate locoweed, and heavy locoweed. We computed average daily gain (ADG) for cattle by pasture and by whether visible signs of locoweed poisoning were apparent at the end of the grazing trial.

In a separate study in 1997, we evaluated differences in average daily gain (ADG) on locoweed infested pastures following several different management options. This study was conducted on the Chesney Ranch, located 12 miles east of Maxwell, N.M. Three groups of yearling steers were used to evaluate alternative management strategies that are called *eat and pull*, *loco and pull*, *rotation*, and *aversion*.

The *eat and pull* strategy requires that cattle be checked frequently to see if they are eating locoweed. Cattle observed eating the poisonous plant are removed from the herd and taken to a locoweed-free area. The *loco and pull* strategy is similar to the *eat and pull*, but is a matter of degree. Cattle are checked less frequently, and only those cattle showing visible signs of poisoning are removed from the pasture. With the *rotation* strategy, cattle are rotated off locoweed-infested areas during early spring and late fall when locoweed is the dominant green forage. For the *aversion* strategy, cattle are fasted overnight and then given freshly chopped locoweed. They are given an emetic (a substance that gives the animals severe stomachaches) after consuming the locoweed. Theoretically, this induced sickness will then be associated with the sight and smell of locoweed, and animals will avoid eating the poisonous plant.

Three groups of cattle were used in the 1997 Chesney Ranch study, including cattle imported from outside the northeastern New Mexico area (66 head), native cattle raised in the area (61 head), and 21 head with mixed backgrounds used in the aversion study. More detailed results for the aversion study will be published elsewhere.

As would be expected, ADG of yearling stocker cattle decreased with increasing amounts of locoweed in the pasture (table 1). Those animals showing visible signs of locoweed poisoning gained half as much as those showing no signs of poisoning. ADGs in pastures with moderate and heavy locoweed infestations were statistically less than when no locoweed was present, but ADG for the moderate and heavy infested pastures were not statistically different from each other. This was expected because animals were removed to a recovery area before severe intoxication occurred.

Averted yearlings gained over 0.50 lb/day more than nonaverted, locoweed eating animals (table 2). For other management strategies, including *eat and pull*, *rotation grazing*, and *loco and pull*, yearlings that had visible signs of poisoning gained about 0.4 lb/head/day less than those without visible signs of poisoning. Over the typical 5 to 6 month grazing season the difference in ADG means an 80 to 100 pound reduction in sale weight.

As described in *Locoweed Poisoning Causes Economic Losses for Yearling Stocker Enterprises* (p. 76), organized meetings and ranch visits with producers were used to further define ADG and sale weight differences for yearling cattle consuming locoweed. Combining what was learned from the grazing trials with information gathered from northeastern New Mexico ranchers, the expected variation in ADG for yearling cattle at three alternative levels of locoweed intoxication was defined (fig. 1). ADGs decline as more locoweed is consumed by the animal. The rate at which ADG declines before rehabilitation begins, or increases after rehabilitation has started, depends on the amount of locoweed the animals have consumed. Given the defined pattern of ADG, weights of nonintoxicated animals increase steadily over the grazing season while weights of moderately and severely intoxicated animals do not (fig. 1). We did not compare performance of animals that were severely intoxicated and received no corrective action to those that did not eat locoweed. Rather, we computed ADG and sale weight recognizing that animals are moved to a locoweed-free area and healed for an extended period once the locoweed problem is observed. That is, we assumed that *loco and pull* management is followed. Ranchers generally agreed that if left untreated, severely intoxicated animals would have died.

At time of sale in mid-October, even with an extended period of supplemental feeding and intensive care, our analysis shows severely intoxicated animals will weigh about 220 pounds less than those that did not become visibly intoxicated by locoweed (fig. 1). Moderately affected animals will weigh about 100 pounds less.

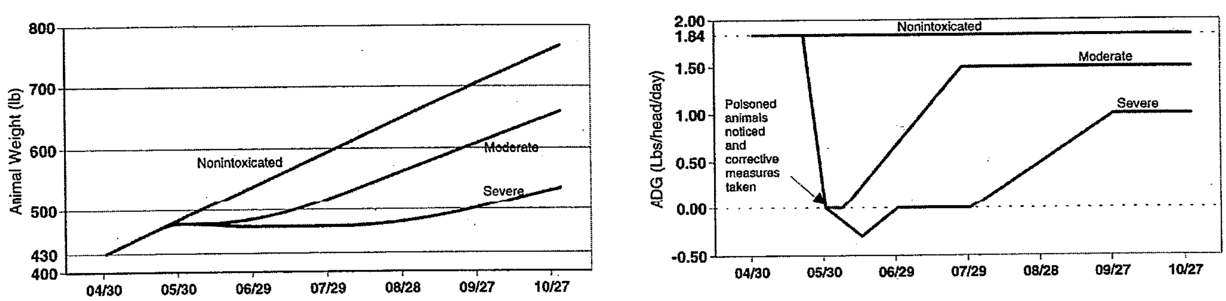


Figure 1. Expected variations in ADG and animal weights over the grazing season.

Table 1. Average daily gain (ADG) for yearling heifers grazing pastures infested with different amounts of locoweed on the Mondragon Ranch, 1996.

		ADG (lb/head/day)	
Amount of locoweed in pasture			
None (Minimal locoweed infestation)		1.77	
Moderate (30% of pasture with 2¼ plants/yd^2)		1.19	
Heavy (62% of pasture with 5¼ plants/yd^2)		1.15	
Visible signs of locoweed poisoning at end of trial			
Yes		0.77	
No		1.55	
Cross comparison		Visible signs	
		Yes	No
Amount of locoweed	None	n/a	1.77
	Moderate	0.63	1.37
	Heavy	0.81	1.50

Table 2. Average daily gain (ADG) for yearling steers with alternative management options and for imported versus native cattle on the Chesney Ranch, 1997.

Management option	Type of cattle	Visually affected by locoweed?	Head	ADG (lbs/head/day)
Averages by grazing management				
Eat and pull	Imported	All	40	1.76
		No	30	1.84
		Yes	10	1.52
Rotation	Native	No	49	1.91
		Yes	0	—
Loco and pull	Imported	All	26	1.71
		No	18	1.86
		Yes	8	1.36
	Native	All	12	1.97
		No	10	2.03
		Yes	2	1.67
Aversion				
Averted and noneaters	Mixed	No	16	1.56
Nonaverted eaters	Mixed	Yes	5	0.98
Averages by Cattle Type				
	Imported		66	1.74
	Native		61	1.92

Les P. Owen is a graduate assistant and L. Allen Torell is a professor and Extension ranch business specialist, both in the Department of Agricultural Economics and Agricultural Business. J. David Graham is a Union County Extension agent in Clayton, N.M. Michael H. Ralphs is a range scientist, U.S. Department of Agriculture, Agricultural Research Service, Poisonous Plant Research Laboratory in Logan, Utah.

ECONOMICS

Locoweed Poisoning Causes Economic Losses for Yearling Stocker Enterprises

Les P. Owen, L. Allen Torell, and J. David Graham

Economic losses from locoweed poisoning vary with the degree of poisoning and are estimated to average $282/head for severely poisoned animals.

Differences in production for cattle poisoned by locoweed have not been quantified and are known to vary considerably from year to year and from ranch to ranch. Thus, much of the information used in developing an economic model for evaluating economic losses from locoweed poisoning is based on the experiences of knowledgeable livestock producers in northeastern New Mexico, as described at meetings and ranch visits held during summer 1997. Grazing trials conducted by various researchers with New Mexico State University and the U.S. Department of Agriculture, Agricultural Research Service (USDA-ARS) provided research-based estimates of animal performance expected with increasing levels of locoweed intoxication and following alternative management options (See *Degree of Locoweed Poisoning Predicts Yearling Stocker Performance*, p. 71).

Estimating economic losses from locoweed poisoning requires definition of key production and economic parameters for a cost and return comparison, including assumptions about expected yearling average daily gain (ADG), the length of time until cattle performance is negatively impacted by locoweed consumption, the expected recovery period once cattle are removed from locoweed infested pastures, and the proportion of the yearling herd intoxicated to different degrees during a typical year. We have detailed these basic assumptions (table 1).

Economic losses from locoweed poisoning were estimated using a "with" and "without" poisoning comparison. This comparison is not made, however, between a situation where the total herd is poisoned as compared to no locoweed poisoning at all. Poisoning of the entire herd is not typical or expected. While widely variable, ranchers estimate that during a typical year, 68% of the herd will not consume locoweed in high enough quantities to significantly impact animal performance. An estimated 25% of the herd will be moderately intoxicated and 7% will be severely poisoned from eating the weed.

Once intoxicated animals are identified, prudent ranchers do not let them continue to eat locoweed. Ranchers generally recognize that to not remove intoxicated animals from the rest of the herd will result in increased and significant economic losses. Therefore, intoxicated animals are generally removed from the main herd. In some cases, animals are removed once they are observed eating the poisonous plant, but the most common strategy is to pull the animals from the pasture once visible signs of locoweed poisoning are observed.

A few ranchers participating in rancher meetings sold intoxicated animals immediately after the poisoning problem was diagnosed, but it was most common to heal the animals in a recovery area with supplementation for 60 to 120 days before sale. The cost of the healing process is considered in the economic comparisons presented below.

The estimated costs and returns for a typical northeastern New Mexico yearling stocker operation are detailed (table 2) with alternative levels of locoweed poisoning. We summarized these differences in costs and returns on a $/head basis for yearlings that are moderately and severely poisoned by locoweed, as compared to yearlings that are not poisoned by the weed. The difference in gross returns ($68 for moderate, $184 for severe) are due to reduced livestock performance and the resulting lighter sale weights. With the assumed *loco and pull* management option in place, yearlings are rehabilitated so that the visual symptoms of locoweed poisoning are gone by the time of sale, thus no price reduction for intoxicated animals was included.

While in recovery, moderately intoxicated steers were assumed to be supplemented with 1 lb/head/day cottonseed cake for 57 days. This results in an added $7/head supplementation cost for cattle in the moderately poisoned category. Severely intoxicated cattle are supplemented with 10 lb/head/day alfalfa and 1 lb/head/day corn for 120 days while in the recovery area. Additional feed costs for severely poisoned animals are then estimated to be $98/head.

Economic losses from locoweed poisoning are substantial and include both reduced sales value and increased production costs. Net ranch income, which measures the net return to operator labor, management, investment, and risk, was reduced by $75/head for moderately poisoned cattle and $282/head for severely poisoned cattle.

Estimated economic losses from locoweed will change from those estimated here as market conditions and input costs change. We evaluated several different beef price situations, including the high price years of 1991 through 1994 and the relatively low price years of 1995 and 1996. Because net returns for yearling operators are determined by the margin between purchase and sale price along with other production costs, and because this average price differential has not changed much recently (except for a narrowing of the margin as prices decreased in 1995 and 1996), the economics of yearling stocker production and the economic losses from locoweed poisoning were estimated to be similar for each of the recent production years. An average of 1990 through 1996 beef prices was used in the economic model.

Economic losses to locoweed poisoning for yearling stocker operations in northeastern New Mexico, 1997.

	Moderate	Severe
	($/head)	
Lost gross revenue from diminished livestock performance	$68	$184
Added costs for rehabilitating locoweed-poisoned animals	7	98
Net difference in net ranch income	75	282

Note: Detailed calculations are shown in table 2. The comparisons for moderate and severe locoweed poisoning are made relative to the nonintoxicated category.

Les P. Owen is a graduate assistant and L. Allen Torell is a professor and Extension ranch business specialist, both in the Department of Agricultural Economics and Agricultural Business. J. David Graham is a Union County Extension agent in Clayton, N.M.

Table 1. Economic model definition for northeastern New Mexico during a typical year.

Model parameter	Definition	
1. Date yearlings are turned out on rangeland	May 1	
2. Sale date	October 15	
3. Length of yearling grazing period	167 days	
4. Number of cattle purchased	550 head	
5. Livestock weights		
a. Weight of cattle at purchase	430 lbs	
b. Weight of cattle at sale	Variable with amount of poisoning	
6. Percent of herd in locoweed intoxication category		
a. Nonintoxicated	68%	
b. Moderate	25%	
c. Severe	7%	
7. Seasonal death loss by intoxication category		
a. Nonintoxicated	1%	
b. Moderate	2%	
c. Severe	3%	
8. Expected ADG (lb/head/day) for nonintoxicated cattle	1.84	
9. Variation in ADG over grazing season for moderately and severely intoxicated cattle.		
Average ADG, moderate (lb/head/day)	1.07	
Average ADG, severe (lb/head/day)	0.42	
Event	**Moderate**	**Severe**
a. Days after entering pasture until ADG is affected by locoweed poisoning	21	21
b. Days with declining ADG	9	24
c. Days after entering pasture until visual signs of poisoning are observed	30	30
d. Days of weight loss (negative ADG)	0	30
e. Minimum ADG	0	-0.30
f. Days until positive gain resumes once moved to recovery area	7	60
g. Days until peak gain is reached on the rebound after moving to recovery area	50	120
h. Maximum ADG during recovery	1.50	1.00
i. Supplemental feeding during recovery	1 lb/head/day of cottonseed cake ($250/ton)	1 lb/head/day of corn ($350/ton) and 10 lb/head/day of alfalfa ($128/ton)
10. Ranch size, inputs used, production costs, and overhead expenses	Various cost categories defined for typical northeast New Mexico ranch	
11. Beef prices		
Base purchase price ($/lb) for 450 lb steer	$0.90	
Base sale price ($/lb) for 650 lb steer	$0.78	

Table 2. Cost and return estimates for *loco and pull* management.

Number	$/CWT	Sale weight (CWT)	Total ($)	$/head purchased No loco	$/head purchased Moderate loco	$/head purchased Severe loco	Weighted average
I. Gross returns							
370 Non-loco steers	$76.00	7.37	$207,244	$554.13			
135 Moderate-loco steers	$78.00	6.35	$66,866		$486.29		
37 Severe-loco steers	$74.00	5.20	$14,238			$369.81	
Total			$288,348	554.13	486.29	369.81	524.27

II. Costs	Unit	$/Unit	Total $	No loco	Guideline value $/head purchased Moderate loco	Severe loco	Average
A. Variable costs							
1. Feed:							
29.2 Purchased hay	Tons	128	3,738	1.63	1.63	78.43	7.01
1.0 Grain	Tons	352	352	0.64	0.64	0.64	0.64
2.2 Corn	Tons	350	777	0.00	0.00	21.00	1.47
3.8 Cottonseed cake	Tons	250	962	0.00	7.13	0.00	1.78
7.7 Protein supplements	Tons	253	1,948	3.54	3.54	3.54	3.54
2.0 Salt	Tons	130	260	0.47	0.47	0.47	0.47
7.0 Minerals	Tons	323	2,261	4.11	4.11	4.11	4.11
Total			10,298	10.39	17.52	108.19	19.02
2. Livestock Expenses:	CWT						
550 Purchased steers	4.30	91.76	217,008	394.56	394.56	394.56	394.56
Miscellaneous other expenses			24,739	44.98	44.98	44.98	44.98
Total			241,747	439.54	439.54	439.54	439.54
Total variable costs			252,044	449.93	457.06	547.73	458.56
B. Fixed costs							
Total fixed costs			21,855	39.74	39.74	39.74	39.74
Total costs			273,899	489.67	496.80	587.47	498.30
C. Net ranch income			14,448	64.46	-10.50	-217.66	25.97
Proportion of yearling purchased				68%	25%	7%	100%

Adapted from medium-sized yearling stocker enterprise budgets presented in the *New Mexico Livestock Cost and Return* series, 1996. Assumes that 550 head of yearling steers are purchased. The feed costs of healing intoxicated animals are included in the appropriated expenses categories.

Healing Locoweed-Poisoned Cattle Before Sale Decreases Economic Losses

L. Allen Torell, Les P. Owen, and J. David Graham

Allowing locoweed-poisoned cattle to recuperate is a better economic choice than immediately selling animals with visible signs of poisoning.

It is discouraging to notice that part of your herd has been into the weed. It is widely recognized that at the very least intoxicated animals must be moved to a locoweed-free area. Then extended rehabilitation with supplemental feeding is required before eventual sale in the fall. Another option is to haul the animals directly to the sale barn. We compared the economics of these two options—immediate sale versus *loco and pull* management, using the economic model described in *Locoweed Poisoning Causes Economic Losses for Yearling Stocker Enterprises*, (p. 76).

According to that article, if *loco and pull* management is practiced and intoxicated animals are moved to a locoweed-free area and supplemented for an extended period of time before sale, net ranch returns are estimated to be $64/head for animals not affected by locoweed poisoning, negative $11/head for moderately intoxicated animals, and negative $217/head for those severely poisoned by locoweed. For locoweed-intoxicated cattle, a loss is expected with the 1990 to 1996 average beef prices used in the enterprise budget assessment. The added cost of the supplements and rehabilitation, and especially the reduced sale weight, eliminates profit for locoweed-intoxicated animals.

Detection of animals eating locoweed is difficult and influenced greatly by how closely cattle are monitored. In this cost comparison, we assume poisoned animals are identified 30 days after entering a locoweed-infested pasture. If sold after this 30-day period, animals purchased at 430 pounds would weigh about 480 pounds. Significant production expenses would already have been incurred as animals were received and prepared for the grazing season. It also would be obvious to knowledgeable buyers that severely intoxicated animals had been into the weed. Correspondingly, northeastern New Mexico ranchers estimate a price discount of 10 to 85% would be expected, depending on the severity of poisoning. In the analysis, we used a 50%-price discount for severely poisoned animals and 10% for those moderately poisoned. This is similar to the estimates provided by Kansas researchers, in which the characteristics and prices received for animals sold at Midwestern livestock auctions were studied. A discount for feeder cattle of 33% was estimated for animals that were stale, sick, and had a rough, dull coat. An additional discount of 46% was noted for animals with lumps, bad eyes, and lameness—conditions that are common for locoweed-poisoned animals.

Immediate sale of poisoned animals results in significantly higher economic losses from locoweed, relative to rehabilitating the animals on the ranch for an extended period before sale (table 1). With 1990 to 1996 average beef prices and with price discounts assumed for intoxicated cattle, the economic loss per animal increases by $103/head for moderately intoxicated animals and by $68 for severely intoxicated animals, if animals are sold immediately instead of rehabilitated. Letting animals heal before sale is clearly a better economic choice.

In our budget assessment, cost items did not include a land charge, because we assumed the rancher had a locoweed-free area on the ranch, and the calculated net ranch income is a residual return to unpaid resources including land (table 1). As assumed in the analysis, a locoweed-free area would be needed for four and one-half months to rehabilitate animals. The added losses from immediate sale suggest a substantial amount could be spent to acquire the needed locoweed-free area.

Table 1. Economic losses to locoweed poisoning for yearling stocker operations in northeastern New Mexico, following alternative marketing strategies ($/head).

	Loco and pull management		Immediate sale		Added loss from immediate sale	
	Moderate	Severe	Moderate	Severe	Moderate	Severe
Gross returns	$486	$370	$376	$204	-110	-166
Added costs for recovering locoweed-poisoned animals	7	98	0	0	7	98
Net difference in net ranch income	-11	-217	-114	-285	-103	-68

Note: Except for supplementation costs, production costs are assumed to be the same as shown in table 2 of *Locoweed Poisoning Causes Economic Losses for Yearling Stocker Enterprises* (p. 76). Many of these costs are incurred at the time of yearling purchase and other variable costs do not substantially change without major changes in herd size. A 10% and 50% sale price discount is assumed for moderately and severely intoxicated animals, respectively.

L. Allen Torell is a professor and Extension ranch business specialist, and Les P. Owen is a graduate assistant, both in the Department of Agricultural Economics and Agricultural Business.
J. David Graham is a Union County Extension agent in Clayton, N.M.

The Economic Value of Having a Locoweed-free Area

L. Allen Torell, Kirk McDaniel, Les P. Owen, and J. David Graham

Rangeland devoid of locoweed is worth nearly $8 per acre. With this relatively high economic value, spraying silky crazyweed is an economically feasible alternative provided the treatment lasts two years.

As shown in *Healing Locoweed-Poisoned Cattle Before Sale Decreases Economic Losses* (p. 80), economic losses from locoweed poisoning increase substantially if poisoned animals are sold immediately and, especially, if they exhibit visible signs of poisoning when sold. A better choice is to heal affected animals on the ranch for an extended period with range forage, supplemental feeds, and extra care. We have called this strategy *loco and pull* management because grazing animals are left in locoweed-infested pastures until visual signs of poisoning are observed, then they are moved to locoweed free areas for rehabilitation.

Through the added effort and expense of *loco and pull* management a net return of $103/head can be recovered for moderately poisoned animals, with 1990 to 1996 average beef prices. Severely poisoned animals do not gain as well and require additional feeding and care, thus, net returns recovered from the healing process are reduced to $68/head (table 1 in *Healing Locoweed-Poisoned Cattle Before Sale Decreases Economic Losses*, p. 80). When the relative number of moderate and severely poisoned animals on the ranch are considered (assumed to be 25% and 7% of the herd, respectively in our analysis) the weighted average value of healing intoxicated animals is estimated to be $95.34/head.

The value of rehabilitation can be converted to a $/acre value by considering the standard stocking rate allowance used in northeastern New Mexico of 15 acres per yearling for a 6-month grazing season. The rehabilitation period assumed in the economic evaluation is 4½ months, thus the equivalent grazing allowance for this shorter grazing season would be 12 acres/head. The $95.34/head rehabilitation value means, then, that the value of a locoweed free area is $7.95/acre ($95.34/head ÷ 12 acres/head). This assumes that a locoweed-free pasture exists on the ranch and poisoned steers and heifers can be moved to this area, fed additional supplements, and rehabilitated before sale in late fall.

In many cases, especially during those years when locoweed infests major areas, northeastern New Mexico ranches do not have locoweed-free pastures. When this is the case, at least three management options exist. First, affected animals can be sold immediately after diagnosing that they are poisoned by locoweed. As discussed above, and as shown in *Healing Locoweed-Poisoned Cattle Before Sale Decreases Economic Losses* (p. 80), this is not the preferred alternative. Substantially more money is lost per head from the early sale of visibly intoxicated animals as compared to healing the animals on the ranch.

A second alternative is to spray locoweed in some pastures and selectively move intoxicated animals to these locoweed-free areas. This requires early planning because locoweed must be removed by spraying before the grazing season begins. It also is important to determine whether silky crazyweed or woolly locoweed is causing the problem. As discussed in *How Long Does Locoweed Control Last?* (p. 62), woolly locoweed is a cyclic plant with a relatively short expected life span. The weevil, *Cleonidius trivittatus* is believed to largely keep woolly locoweed from being a persistent problem (see *Common Loco-*

weed-Feeding Insects, p. 42). Silky crazyweed, however, is long-lived and can be expected to persist without control.

Using one of the recommended spray treatments, the cost of chemical control is estimated to average $14 to $16/acre with aerial application. As shown in *Controlling Locoweeds with Herbicides* (p. 52), excellent control of the poisonous plant can be expected and treatments will generally last from 2 to 6 years. As shown above, the annual economic benefit of having a locoweed-free area is estimated to average $7.95/acre. This means a herbicide treatment must last at least two years (the year of control plus one more) for the treatment to be economically feasible. If the spray treatment is made the previous fall, or in the spring before the start of the grazing season, and the treatment provides a locoweed-free area for two years, a 12.6% rate of return would be realized on the investment.

Leasing locoweed-free rangeland from a fortunate neighbor is another way that locoweed intoxicated animals can be healed. Considering forage value to be the amount of added losses from forced sale of intoxicated animals if alternative locoweed-free forage is not found, ranchers could afford to spend more than $23/month/head to lease locoweed-free forage for moderately poisoned animals and $15/month/head for severe ($103 ÷ 4½ months = $22.88/month/head for moderately poisoned animals and $68 ÷ 4½ months = $15.11/month/head for severely poisoned animals). Average rangeland lease rates with care of cattle provided are currently less than these amounts.

As described by northeastern New Mexico ranchers at meeting held in summer 1997, about a third of the herd will likely become intoxicated with locoweed to some degree during a typical year. This suggests that every 150 yearlings purchased will potentially require a section (640 acres) of rangeland that is locoweed-free. Or, given the annual variability in the degree of the locoweed problem, about one quarter to one third of the ranch needs to remain locoweed-free for rehabilitation of locoweed intoxicated animals before sale.

L. Allen Torell is a professor and Extension ranch business specialist, and Les P. Owen is a graduate assistant, both in the Department of Agricultural Economics and Agricultural Business. Kirk McDaniel is a professor of range science in the Department of Animal and Range Sciences. J. David Graham is a Union County Extension agent in Clayton, N.M.

Averting Cattle from Consuming Locoweed Can Save Money

Les P. Owen, L. Allen Torell, Michael H. Ralphs, and J. David Graham

Conditioning cattle to avoid eating locoweed is estimated to increase net ranch returns by $32 per head.

Cattle can be trained to avoid eating certain plants through a process known as conditioned feed aversion. Cattle and other animals associate sickness with ingesting certain feeds. By feeding cattle fresh locoweed and then dosing them with an emetic, such as lithium chloride, to induce sickness, they have been trained to avoid eating locoweed. In fact, present and past research has shown a high success rate for training cattle to avoid eating poisonous plants using the feed aversion technique.

The economic model described in *Locoweed Poisoning Causes Economic Losses for Yearling Stocker Enterprises* (p. 76) was used to estimate the potential benefits of averting stocker cattle. The economic model assumes that the *aversion* process is 100% successful, meaning that all averted cattle will remain nonintoxicated throughout the grazing season. Research shows this is the expected result for naive cattle that have not previously eaten locoweed. Cattle that have eaten locoweed and consider it an acceptable feed require two or three treatments before they will stop eating the weed.

We compared the economics of *feed aversion* to what we have called *loco and pull* management, where intoxicated cattle are removed from the herd and given feed supplements to rehabilitate them from the visual symptoms of locoism before sale. A detailed budget for *loco and pull* management is presented in *Locoweed Poisoning Causes Economic Losses for Yearling Stocker Enterprises* (p. 76). With this option, locoweed-eating cattle are allowed to become intoxicated by the poisonous weed and then additional costs are incurred to rehabilitate these animals.

We assumed that no animals would begin to eat locoweed, and rehabilitation of poisoned animals would not be required following the aversion treatment. This treatment requires that fresh locoweed be harvested and presented to hungry animals. Care must be taken to assure that the resulting sickness is associated with the consumption of locoweed and not a desirable forage species. Thus, animals are confined overnight and observed until the locoweed is consumed. They are then given 200 mg/kg of body weight of lithium chloride to induce sickness. The lithium chloride treatment and the labor to harvest the locoweed, administer the treatment, and monitor cattle is estimated to cost $7/head. The economic payoff from the treatment is that no animals in the herd become poisoned by locoweed.

The net economic benefit from averting cattle was estimated to be $32/head treated. As shown in table 1, this results largely from the added livestock sales from averted animals, but an estimated $2/head cost savings also results. This savings occurs because the cost of the aversion was $2/head less than the supplemental feed costs that would have been required to rehabilitate intoxicated animals without the aversion treatment. This will be highly variable, however, and will depend on the cost of supplemental feeds and how many animals would have been poisoned without the aversion treatment. We assumed 25% and 7% of the herd would have been moderately and severely poisoned without the aversion treatment. It is the improved performance of this part of the herd that economically justifies the aversion treatment.

In the economic model, we decreased the proportion of the herd potentially affected by locoweed from the assumed levels defined above, while keeping the relative number of moderately and severely poisoned animals the same. By doing this, we could determine at what point the *aversion* treatment and *loco and pull* management would be economically equivalent. We estimate that if more than 9% of the herd (7% moderate and 2% severe) would have been poisoned by locoweed, the *feed aversion* treatment would be superior to the *loco and pull* management strategy. At levels below this point, the cost of averting the entire herd would be greater than the production losses realized given the small number of animals that would have been poisoned.

Table 1. Economic benefits of conditioned feed aversion.

	Loco and pull management	Feed aversion treatment ($/head purchased)	Benefit of aversion
Gross returns	524	555	31
Supplement feed costs for rehabilitation	-9	0	9
Cost of aversion	0	-7	-7
Net ranch income	26	58	32

Note: Estimates for the *loco and pull* strategy are a weighted average over the entire herd by percent of yearlings in each intoxication category. The *aversion* estimates are based on the total herd remaining as nonintoxicated but with a $7/head cost for the aversion.

Les P. Owen is a graduate assistant and L. Allen Torell is a professor and Extension ranch business specialist, both in the Department of Agricultural Economics and Agricultural Business. Michael H. Ralphs is a range scientist, U.S. Department of Agriculture, Agricultural Research Service, Poisonous Plant Research Laboratory in Logan, Utah. J. David Graham is a Union County Extension agent in Clayton, N.M.

Recent Locoweed Publications

Allison, C. D. 1991. Livestock poisoning plants of New Mexico rangelands. NMSU Coop. Ext. Circular 531.

Allison, C. D. 1988. Locoweeds and livestock poisoning. NMSU Coop. Ext. 400-B-15.

Allison, C. D. 1988. Minimizing poisonous plant impact on grazing cattle. p. 29-33. *In:* Livestock Research Briefs and Cattle Growers Short Course. NMSU Agric. Exp. Sta.

Allred, K. W. 1991. The biology of *Astragalus allochrous:* halfmoon locoweed (var. *allochrous)* and Wooton's locoweed (var. *playanus*). NMSU Agr. Exp. Sta. Res. Rpt. 652.

Allred, K. W. 1993. Revision of "An annotated checklist of poisonous or injurious range plants of New Mexico." NMSU Coop. Ext. 400 B-14. 29 p.

Braun, K., T. Cook and C.M. Liddell. 1997. Locoism of cattle in New Mexico caused by a species of *Alternaria?* Phytopath. 87:S11.

Braun, K. and C. M. Liddell. 1998. Locoism in cattle produced by a fungal endophyte? Phytopath. 88:S10.

Campanella, M. C., T. M. Sterling, and D. C. Thompson. 1997. The effects of *Walshia miscecolorella* feeding on swainsonine concentrations in silky crazyweed. Proc. Western Soc. Weed Sci. 50:23-24.

Fox, W. E. and K. W. Allred. 1994. A bibliography of the plant genera *Astragalus* and *Oxytropis* (Fabaceae). New Mexico Agr. Exp. Sta. Res. Rpt. 686.

Fox, W. E., K. W. Allred, and E. H. Roalson. 1998. A guide to common locoweeds and milkvetches of NMSU. New Mexico Coop. Ext. Circ. 557. 94 pp.

Galyean, M. L., M. H. Ralphs, M. N. Reif, J. D. Graham, and W. E. Braselton Jr. 1996. Effects of previous grazing treatment and consumption of locoweed on liver mineral concentrations in beef steers. J. Anim. Sci. 74:827-833.

Holyoak, G. R., S. Wang, K. E. Panter, G. Liu, R. C.Evans, and T. D. Bunch, 1998. The effects of swainsonine on *in vitro* fertilization of bovine oocytes. Annual Intl. Embryo Transfer Society Meeting, Theriogenology 49.

Huddleston, E. W., A. J. Hewitt, T. M. Ledson, R. Sanderson, J. B. Ross, and R. L. Steiner. 1995. Polymer formulation and concentration effects on droplet spectra in simulated aerial sprays. pp. 132-137. *In:* Gaskin, R. E. (ed.). Proc. 4th Intl. Symp. on Adjuvants and Agrochemicals, New Zealand Forestry Research Inst. Bull. 193.

James, L. F., M. H. Ralphs, K. E. Panter, B. L. Stegelmeier, J. A. Pfister, and R. J. Molyneux. 1998. Locoweed research to reduce poisoning on western U.S. rangelands. pp. 19-22. *In:* Garland, T. and A.C. Barr (eds.). Toxic plants and other natural toxicants, CAB International, Oxon, UK.

Jochem, H. J. and T. M. Sterling. 1993. Mechanisms of differential tolerance to picloram and metsulfuron in locoweed. Proc. Western Soc. Weed Sci. 46:8-9.

Knight, J. L. and D. C. Thompson. 1996. Effects of controlling rangeland insect pests on natural enemies of a perennial rangeland weed. Proc. Western Soc. Weed Sci. 49:47.

Ledson, T. M., E. W. Huddleston, and R. Sanderson. 1996. Surfactant effects on aerial spray droplet spectra. *In:* Collins, H. M., F. R. Hall, and M. Hopkins (eds.). Pesticide formulations and application systems: 15th Volume. American Society for Testing and Materials. STP 1269.

Ledson, T. M., D. K. Giles, E. W. Huddleston, and J. Ross. 1996. Droplet spectra from hydraulic nozzles using flow control. ASAE Paper No. AA96-002.

May, T., C. M. Liddell, J. L. Riggs, T. Cook, K. Braun, and E. S. Woodruff. 1997. The role of microorganisms in locoweed toxicity. 24th Biennial Conf. on Rumen Function, Chicago, IL. vol. 24, p. 25.

Morgan, M. and T. May. 1997. The potential for swainsonine biotransformation or utilization by ruminal microorganisms. 24th Biennial Conf. on Rumen Function, Chicago, IL. vol. 24, p. 25.

McDaniel, K. C. 1994. Spring versus fall application of herbicides for silky crazyweed control. Western Soc. Weed Sci. Res. Rpt. p. 9.

McDaniel, K. C. 1995. Silky crazyweed, broom snakeweed, and fringe sage control with herbicides in northern New Mexico. Western Soc. Weed Sci. Res. Rpt. p. 40.

McDaniel, K. C. 1995. Woolly locoweed and broom snakeweed control with various herbicides. Western Soc. Weed Sci. Res. Rpt. p. 30.

McDaniel. K. C. 1996. Locoweed herbicide control program. pp. 11-16. *In*: Locoweed and Broom Snakeweed Research Update. Clayton, NM. Feb. 9, 1996. NMSU Agric. Exp. Sta.

McDaniel, K. C. 1996. Response to 1983 locoweed ranch survey. pp. 31-33. *In*: Locoweed and Broom Snakeweed Research Update. Clayton, NM. Feb. 9, 1996. NMSU Agric. Exp. Sta.

McDaniel, K. C., J. D. Graham, and C. R. Hart. 1998. Silky crazyweed (*Oxytropis sericea*) control on northeastern New Mexico rangeland. Weed Sci. (In review).

McDaniel, K. C., C. R. Hart, and J. D. Graham. 1996. Silky crazyweed control during various growth stages. Western Soc. Weed Sci. Res. Rpt. p. 2.

Owen, L.P., L.A. Torell, K.C. McDaniel, and J.D. Graham. 1999. *Economic Losses and Management of Locoweed Infested Rangeland in Northeastern New Mexico. In*: E.T. Bartlett (ed). Range Economics Symposium proceedings held in conjunction with Range Society Meetings, Omaha, Neb., Feb. 1999. (In Press)

Panter, K. E., T. D. Bunch, L. F. James, and D. V. Sisson. 1987. Ultrasonographic imaging to monitor fetal and placental developments in ewes fed locoweed (*Astragalus lentiginosus*). Amer. J. Vet. Res. 48:686-690.

Panter, K. E., L. F. James, and W. J. Hartley. 1989. Transient testicular degeneration in rams fed locoweed (*Astragalus lentiginosus*). Vet. Hum. Toxicol. 31:42-46.

Panter, K. E., L. F. James, and H. F. Mayland. 1995. Reproductive response in ewes fed alfalfa pellets containing sodium selenate or *Astragalus bisulcatus* as a selenium source. Vet. Hum. Toxicol. 37:30-32.

Parreira, J. A., M. O. Waugh, and T. M. Sterling. 1993. Restriction fragment length polymorphism analysis of two locoweed species. Proc. Western Soc. Weed Sci. 46:9.

Pfister, J. A., J. B. Astorga, K. E. Panter, and R. J. Molyneux. 1993. Maternal locoweed exposure in utero and as a neonate does not disrupt taste aversion learning in lambs. Appl. Anim. Behav. Sci. 36:159-167.

Pfister, J. A. and K. Price. 1996. Lack of maternal influence on lamb consumption of locoweed. J. Anim. Sci. 74:340-344.

Pfister, J. A., B. L. Stegelmeier, C. D. Cheney, L. F. James, and R. J. Molyneux. 1996. Operant analysis of chronic locoweed intoxication in sheep. J. Anim. Sci. 74:2622-2632.

Pomerinke, M. A. 1993. Bionomics of two root feeding weevils (Coleoptera: Curculionidae) on *Astragalus mollissimus* (Fabaceae). M.S. Thesis, New Mexico State University, Las Cruces.

Pomerinke, M. A. and D. C. Thompson. 1995. *Cleonidius trivittatus* feeds exclusively on woolly locoweed in northeastern New Mexico. Southwest. Entomol. 20:107-109.

Pomerinke, M. A., D. C. Thompson, and D. L. Clason. 1995. Bionomics of the four-lined locoweed weevil (Coleoptera: Curculionidae): A native biological control of purple locoweed. Environ. Entomol. 24:1696-1702.

Ralphs, M. H., J. D. Graham, G. Duff, B. L. Stegelmeier, and L. F. James. 1999. Impact of locoweed poisoning on grazing steer weight gains. J. Range Manage. (In press).

Ralphs, M. H., J. D. Graham, M. L. Galyean, and L. F. James. 1997. Creating aversions to locoweed in naive and familiar cattle. J. Range Manage. 50:361-366.

Ralphs, M. H., J. D. Graham, M. L. Galyean, and L. F. James. 1997. Influence of over-wintering feed regimen on consumption of locoweed by steers. J. Range Manage. 50:250-252.

Ralphs, M. H., J. D. Graham, and L. F. James. 1994. Cattle grazing white locoweed in New Mexico: influence of grazing pressure and phenological growth state. J. Range Manage. 47:270-274.

Ralphs, M. H., J. D. Graham, and L. F. James. 1994. Social facilitation influences cattle to graze locoweed. J. Range Manage. 47:123-126.

Ralphs, M. H., J. D. Graham, R. J. Molyneux, and L. F. James. 1993. Seasonal grazing of locoweeds in northeastern New Mexico. J. Range Manage. 46:416-420.

Roalson, E. H. and K. W. Allred. 1997. Atlas of New Mexico *Astragalus* and *Oxytropis*. NMSU Agric. Exp. Sta. Res. Rpt. 715. 23 p.

Sanderson, R., A. J. Hewitt, E. W. Huddleston, and J. B. Ross. 1994. Polymer and invert emulsifying oil effects on droplet size spectra. J. Environ. Sci. and Health. B29:815-829.

Smith, G. S., K. W. Allred, and D. E. Kiehl. 1992. Swainsonine content of locoweeds in New Mexico. p. 78. *In:* Livestock Research Briefs and Cattle Growers Short Course. NMSU Agric. Exp. Sta.

Stegelmeier, B. L., L. F. James, K. E. Panter, D. R. Gardner, M. H. Ralphs, and J. A. Pfister. 1998. Tissue swainsonine clearance in sheep chronically poisoned with locoweed. J. Anim. Sci. 76:1140-1144.

Stegelmeier, B. L., P. W. Snyder, L. F. James, K. E. Panter, R. J. Molyneux, D. R. Gardner, M. H. Ralphs, and J. A. Pfister. 1998. The immunologic and toxic effects of chronic locoweed (*Astragalus lentiginosus*) intoxication in cattle. pp. 285-290. *In:* Garland, T. and A. C. Barr (eds.). Toxic plants and other natural toxicants. CAB International, Oxon, UK.

Sterling, T. M. and H. J. Jochem. 1995. Uptake, translocation and metabolism of picloram and metsulfuron by two genera of locoweed. Weed Sci. 43:13-17.

Sterling, T. M. and N. K. Lownds. 1996. Factors affecting herbicide activity in snakeweed and locoweed. pp. 16-17. *In:* Locoweed and Broom Snakeweed Research Update. Clayton, NMSU. Feb. 9, 1996. NM Agric. Exp. Sta.

Sterling, T. M., J. A. Parreira, and D. C. Thompson. 1994. Consumption differences among woolly loco varieties by a specialist weevil. Proc. Western Soc. Weed Sci. 47:17.

Strickland, J. R., T. T. Ross, and J. B. Taylor. 1998. New (and old) research on poisonous plant toxicities in livestock. pp. 23-28. *In:* Livestock Research Briefs and Cattle Growers Short Course. NMSU Agric. Exp. Sta.

Strickland, J. R., J. B. Taylor, M. L. Galyean, and G. C. Duff. 1996. Effects of swainsonine on *in vitro* lymphocyte proliferation. pp. 18-22. *In:* Locoweed and Broom Snakeweed Research Update. Clayton, NM. Feb 9, 1996. NM Agric. Exp. Sta.

Strickland, J. R., J. B. Taylor, D. E. Hawkins, and T. May. 1998. *In vivo* effect of locoweed consumption on serum clinical profiles of sheep in a nutrient restricted state. Proc. Western Sec. Amer. Soc. Anim. Sci. 49: 44-48.

Taylor, J. B., J. Nordyke, L. F. Gulino Klein, and J. R. Strickland. 1997. *In vitro* effect of swainsonine on bovine and ovine lymphoblastogenesis. Proc. Western Sec. Amer. Soc. Anim. Sci. 48:41-44.

Taylor, J. B. and J. R. Strickland. 1998. *In vitro* effect of swainsonine on bovine and ovine lymphoblastogenesis. J. Anim. Sci. (In press)

Taylor, J. B., J. R. Strickland, L. F. Gulino, and J. G. Nordyke. 1997. *In vitro* effects of swainsonine on bovine and ovine lymphoblastogenesis. p. 70. *In:* Livestock Research Briefs and Cattle Growers Short Course. NMSU Agric. Exp. Sta.

Taylor, J. B., J. R. Strickland, D. E. Hawkins, and T. May. 1997. Effects of low level locoweed consumption on ovine immunocompetence. p.71. *In:* Livestock Research Briefs and Cattle Growers Short Course. NMSU Agric. Exp. Sta.

Taylor, J. B., J. R. Strickland, D. E. Hawkins, and T. May. 1998. *In vivo* effect of locoweed consumption on immunocompetence and serum swainsonine concentrations of sheep in a nutrient restricted state. p. 79. *In:* Livestock Research Briefs and Cattle Growers Short Course. NMSU Agric. Exp. Sta.

Taylor, J. B., J. R. Strickland, D. E. Hawkins, and T. May. 1998. *In vivo* effect of locoweed on immunocompetence and serum swainsonine concentrations of sheep in a nutrient restricted state. Proc. Western Sec. Amer. Soc. Anim. Sci. 49:49-52.

Taylor, J. B., J. R. Strickland, D. E. Hawkins, and T. May. 1998. *In vivo* effect of locoweed consumption on serum clinical profiles of sheep. p. 79. *In:* Livestock Research Briefs and Cattle Growers Short Course. NMSU Agric. Exp. Sta.

Thompson, D. C. 1994. Managing native insects for the biological control of weeds. Proc. Southern Weed Sci Soc. 47:154-155.

Thompson, D. C., J. L. Knight, T. M. Sterling and L. W. Murray. 1995. Preference for specific varieties of woolly locoweed by a specialist weevil, *Cleonidius trivittatus* (Say). Southwest. Entomol. 20:325-333.

Thompson, D. C., J. A. Parreira, and T. M. Sterling. 1994. Consumption differences among woolly loco varieties by a specialist weevil. Proc. Western Soc. Weed Sci. 47:18.

Torell, L.A., L.P. Owen, K.C. McDaniel, and J.D. Graham. 1999. *Production and Marketing Strategies to Minimize Economic Losses from Locoweed Poisoning.* J. Range Manage. (In review).

Wang, S., Holyoak, G. R., Panter, K. E., Liu, G., Evans, R. C., and Bunch, T. D. 1998. Resazurin reduction assay for ram sperm metabloic activity measured by spectrophotometry. Proc. Soc. Exper. Biol. Med. 217:197-202.